



Energy, Mines and  
Resources Canada

Énergie, Mines et  
Ressources Canada

## CANMET

Canada Centre  
for Mineral  
and Energy  
Technology

Centre canadien  
de la technologie  
des minéraux  
et de l'énergie

### ANISOTROPIC PROPERTIES STUDIES OF LAC DU BONNET GRANITE SPECIMENS: REPORT # 3

RAND JACKSON

ROCK MECHANICS LABORATORY

NOVEMBER 1986

This document is an unclassified  
mineral and energy technology  
report prepared for the  
Department of Energy, Mines and  
Technical Development  
the purpose of which is to provide  
information on the technology  
(CANMET)

Ce document est un rapport  
non classifié et est rédigé  
pour le ministère de l'Énergie,  
des Mines et de la Technologie  
à l'effet de fournir des renseignements  
sur la technologie des minéraux et de  
l'énergie (CANMET)

95 pp  
MINERAL AND ENERGY TECHNOLOGY  
MINING RESEARCH LABORATORIES  
DIVISIONAL REPORT M&ET/MRL 86-142 (TR)

MICROMEDIA

## ANISOTROPIC PROPERTIES STUDIES OF LAC DU BONNET GRANITE SPECIMENS:

## REPORT # 3

by

R. Jackson\*

## ABSTRACT

Compressive and shear wave velocity measurements, as well as uniaxial compression testing, was conducted on samples obtained from boreholes 001-072-MOD1, 001-072-MOD2, 001-228-MOD1, 001-228-MOD2, 001-275-MOD1 and 001-275-MOD2 located in the Lac du Bonnet batholith near Pinawa, Manitoba. The purpose of the studies is to ascertain if any anisotropy in terms of the uniaxial mechanical properties exists in the Lac du Bonnet samples and, if so, to what extent.

This represents the third in a series of reports to be published as data becomes available. A final report containing detailed analysis of the results will be written after all the samples suites have been tested.

Keywords: Anisotropy, Rock Properties, Mechanical, Young's Modulus, Poisson's Ratio, Uniaxial Compressive Strength, Velocity, Lac du Bonnet

---

\*Research Officer, Mining Research Laboratories, CANMET, Energy, Mines and Resources Canada, Ottawa, Ontario.

ÉTUDE DES PROPRIÉTÉS ANISOTROPIQUES DES ÉCHANTILLONS DE GRANIT  
PROVENANT DU LAC DU BONNET : RAPPORT N° 3

par

R. Jackson\*

RÉSUMÉ

La mesure de la vitesse de l'onde de compression et de cisaillement de même que le contrôle de la compression uniaxiale ont été effectués sur des échantillons provenant des trous de forage 001-072-MOD1, 001-072-MOD2, 001-228-MOD1, 001-228-MOD2, 001-275-MOD1 et 001-275-MOD2 situés dans le batholite du Lac du Bonnet, près de Pinawa, au Manitoba. Ces études visaient à découvrir si les échantillons du Lac Bonnet présentent une anisotropie sur le plan des propriétés mécaniques uniaxiales et, le cas échéant, dans quelle mesure.

Le présent rapport est le troisième d'une série de rapports devant être rédigés dès que les données seront disponibles. Un rapport final comprenant une analyse détaillée des résultats sera rédigé dès que le contrôle de la série d'échantillons sera terminé.

Mots clé : Anisotropie, Propriétés des roches, Mécaniques, Module Young (Module d'élasticité), Coefficient de Poisson, Résistance à la compression uniaxiale, vitesse, Lac du Bonnet

---

\*Agent de recherche, Laboratoires de recherche minière, CANMET, Énergie, Mines et Ressources Canada, OTTAWA (Ontario).

## CONTENTS

|                                                | <u>Page</u> |
|------------------------------------------------|-------------|
| ABSTRACT .....                                 | i           |
| RESUME .....                                   | 11          |
| 1. INTRODUCTION .....                          | 1           |
| 2. IDENTIFICATION OF SPECIMENS AND TESTS ..... | 2           |
| 3. DESCRIPTION OF TEST MEASUREMENTS .....      | 3           |
| 4. DATA TREATMENT .....                        | 4           |
| 5. DATA SUMMARY .....                          | 5           |
| 6. FAILURE CHARACTERISTICS .....               | 5           |
| 7. ACKNOWLEDGEMENTS .....                      | 6           |
| 8. REFERENCES .....                            | 6           |
| APPENDIX A                                     | 67-88       |

## TABLES

| <u>No.</u> |                                                                    |    |
|------------|--------------------------------------------------------------------|----|
| 1.         | Summary of sample depth, dimensions, density and orientation ..... | 7  |
| 2.         | Summary of ultrasonic velocity properties .....                    | 9  |
| 3.         | Summary of uniaxial compression properties .....                   | 12 |

## FIGURES

|    |                                                                                                                          |    |
|----|--------------------------------------------------------------------------------------------------------------------------|----|
| 1. | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-072-MOD1, Depth = 1.290 m) ..... | 14 |
| 2. | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-072-MOD1, Depth = 1.345 m) ..... | 15 |
| 3. | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-072-MOD1, Depth = 1.395 m) ..... | 16 |
| 4. | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-072-MOD1, Depth = 1.448 m) ..... | 17 |
| 5. | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-072-MOD1, Depth = 1.460 m) ..... | 18 |
| 6. | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-072-MOD1, Depth = 1.855 m) ..... | 19 |
| 7. | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-072-MOD1, Depth = 2.058 m) ..... | 20 |

## FIGURES (Cont'd)

| <u>No.</u>                                                                                                                   | <u>Page</u> |
|------------------------------------------------------------------------------------------------------------------------------|-------------|
| 8. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-072-MOD1, Depth = 2.158 m) .....  | 21          |
| 9. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-072-MOD1, Depth = 2.283 m) .....  | 22          |
| 10. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-072-MOD2, Depth = 1.497 m) ..... | 23          |
| 11. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-072-MOD2, Depth = 1.550 m) ..... | 24          |
| 12. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-072-MOD2, Depth = 1.604 m) ..... | 25          |
| 13. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-072-MOD2, Depth = 1.659 m) ..... | 26          |
| 14. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-072-MOD2, Depth = 1.667 m) ..... | 27          |
| 15. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-072-MOD2, Depth = 1.759 m) ..... | 28          |
| 16. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-072-MOD2, Depth = 2.132 m) ..... | 29          |
| 17. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-072-MOD2, Depth = 2.215 m) ..... | 30          |
| 18. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-072-MOD2, Depth = 2.309 m) ..... | 31          |
| 19. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-228-MOD1, Depth = 3.414 m) ..... | 32          |
| 20. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-228-MOD1, Depth = 3.470 m) ..... | 33          |
| 21. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-228-MOD1, Depth = 3.525 m) ..... | 34          |
| 22. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-228-MOD1, Depth = 3.580 m) ..... | 35          |
| 23. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-228-MOD1, Depth = 3.590 m) ..... | 36          |

## FIGURES (Cont'd)

| <u>No.</u>                                                                                                                                        | <u>Page</u> |
|---------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| 24. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-228-MOD1, Depth = 3.690 m) .....                      | 37          |
| 25. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-228-MOD1, Depth = 3.695 m) .....                      | 38          |
| 26. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-228-MOD1, Depth = 3.835 m) .....                      | 39          |
| 27. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-228-MOD1, Depth = 4.180 m) .....                      | 40          |
| 28. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-228-MOD2, Depth = 3.488 m) .....                      | 41          |
| 29. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-228-MOD2, Depth = 3.543 m) .....                      | 42          |
| 30. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-228-MOD2, Depth = 3.598 m) .....                      | 43          |
| 31. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-228-MOD2, Depth = 3.653 m) .....                      | 44          |
| 32. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-228-MOD2, Depth = 3.674 m) .....                      | 45          |
| 33. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-228-MOD2, Depth = 3.791 ( $\pi = 60^\circ$ ) m) ..... | 46          |
| 34. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-229-MOD2, Depth = 3.791 ( $\pi = 30^\circ$ ) m) ..... | 47          |
| 35. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-228-MOD2, Depth = 3.943 m) .....                      | 48          |
| 36. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-228-MOD2, Depth = 4.342 m) .....                      | 49          |
| 37. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-275-MOD1, Depth = 1.850 m) .....                      | 50          |
| 38. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-275-MOD1, Depth = 1.905 m) .....                      | 51          |
| 39. Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-275-MOD1, Depth = 1.960 m) .....                      | 52          |

## FIGURES (Cont'd)

| <u>No.</u> |                                                                                                                          | <u>Page</u> |
|------------|--------------------------------------------------------------------------------------------------------------------------|-------------|
| 40.        | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-275-MOD1, Depth = 2.015 m) ..... | 53          |
| 41.        | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-275-MOD1, Depth = 2.033 m) ..... | 54          |
| 42.        | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-275-MOD1, Depth = 2.144 m) ..... | 55          |
| 43.        | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-275-MOD1, Depth = 2.146 m) ..... | 56          |
| 44.        | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-275-MOD1, Depth = 2.296 m) ..... | 57          |
| 45.        | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-275-MOD1, Depth = 2.715 m) ..... | 58          |
| 46.        | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-275-MOD2, Depth = 1.852 m) ..... | 59          |
| 47.        | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-275-MOD2, Depth = 1.907 m) ..... | 60          |
| 48.        | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-275-MOD2, Depth = 1.962 m) ..... | 61          |
| 49.        | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-275-MOD2, Depth = 2.032 m) ..... | 62          |
| 50.        | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-275-MOD2, Depth = 2.145 m) ..... | 63          |
| 51.        | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-275-MOD2, Depth = 2.147 m) ..... | 64          |
| 52.        | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-275-MOD2, Depth = 2.294 m) ..... | 65          |
| 53.        | Axial and circumferential stress/strain curves for anisotropy specimens (Drill Hole 001-275-MOD2, Depth = 2.674 m) ..... | 66          |

## 1. INTRODUCTION

As part of the Canadian Nuclear Fuel Waste Management Project (NFWMP), Atomic Energy of Canada Limited (AECL) is characterizing various rock formations to determine their suitability for long term disposal of high level wastes. The program also includes the construction of an underground research laboratory (URL) near Pinawa, Manitoba to provide an opportunity for extensive in situ investigations.

Biaxial testing conducted on core obtained during the construction phase of the URL has indicated that the rock may be anisotropic in terms of modulus of elasticity (1). It was felt that further study in the form of acoustic velocity and uniaxial compression testing could provide additional insight into this behaviour. The program is currently ongoing and will continue as new samples are obtained from the URL site.

This report represents the third of a series of reports which will be published as new data becomes available. No attempt will be made to analyze the data until the program is completed.

## 2. IDENTIFICATION OF SPECIMENS AND TESTS

Fifty four samples were used for this test series: 9 from each of drill holes 001-072-MOD1, 001-072-MOD2, 001-228-MOD1 and 001-228-MOD2, 001-275-MOD1 and 001-275-MOD2. Unfortunately, sample 2.007 ( $\alpha = 90^\circ$ ,  $\beta = 90^\circ$ ) from borehole 001-275-MOD2 was damaged during sample preparation and could not be used for testing. The location and orientation of the drill holes can be found in Appendix A and are summarized below:

|               |                     |                            |
|---------------|---------------------|----------------------------|
| 001-072-MOD1: | Collar Coordinates: | N 5,570,77.032             |
|               |                     | E 295,787.329              |
|               |                     | elev. 73.518               |
|               | Orientation:        | Plunge (dip): -00.20° (up) |
|               |                     | Trend (direction): 040.98° |
| 001-072-MOD2: | Collar Coordinates: | N 5,570,475.026            |
|               |                     | E 295,787.969              |
|               |                     | elev. 73.308               |
|               | Orientation:        | Plunge (dip): -00.39° (up) |
|               |                     | Trend (direction): 101.04° |

001-228-MOD1: Collar Coordinates: N 5,570,473.089  
E 295,785.897  
elev. 228.546  
Orientation: Plunge (dip): -01.16° (up)  
Trend (direction): 158.72°

001-228-MOD2: Collar Coordinates: N 5,570,473.277  
E 295,787.783  
elev. 228.327  
Orientation: Plunge (dip): -01.32° (up)  
Trend (direction): 062.09°

001-275-MOD1: Collar Coordinates: N 5,570,474.047  
E 295,786.956  
elev. 275.626  
Orientation: Plunge (dip): -01.26° (up)  
Trend (direction): 155.12°

001-275-MOD2: Collar Coordinates: N 5,570,476.094  
E 295,787.377  
elev. 275.634  
Orientation: Plunge (dip): 00.00°  
Trend (direction): 067.38°

The 45 mm diameter test specimens were prepared by recoring the 200 mm cores obtained from the drill holes along the axes of interest. The specimens were then identified according to their location and orientation as follows:

- a) depth of the collar of the 45 mm hole from the collar of the 200 mm hole;
- b) angle  $\theta$  gives the location of the collar of the 45 mm hole around the circumference of the 200 mm core. The angle is measured clockwise (looking down hole) from the orientation mark on the top of the core;
- c) angle  $\alpha$  is the angle between the core axis of the 45 mm core and the 200 mm core. The angle is measured clockwise (i.e., dip) from the down hole direction of the 200 mm core.

Table 1 provides a summary of the specimen depth, dimensions, density and orientation. The following properties were determined for the samples listed:

1. compressive wave velocity;
2. shear wave velocity;
3. dynamic shear modulus,  $G_d$ ;
4. dynamic Young's modulus,  $E_d$ ;
5. Poisson's ratio (determined using velocity data),  $\nu_d$ ;
6. uniaxial compressive strength;
7. Poisson's ratio,  $\nu$ ;
8. tangent modulus of elasticity,  $E_t$ ; and
9. secant modulus of elasticity,  $E_s$ .

### 3. DESCRIPTION OF TEST MEASUREMENTS

Compression and shear wave velocity measurements were carried out on samples already gauged for elastic deformation measurement. The testing equipment consisted of: transmitting and receiving platens containing piezoelectric transducers, a high voltage pulse generator, a signal amplifier and a Tektronix Type 555 dual beam oscilloscope equipped with delay sweep and a time base resolution of 0.01 micro-seconds. The zero time delay was determined by measuring the time of wave arrival across three steel samples of different lengths. These arrival times could then be extrapolated to correspond to a specimen of zero length.

For an outline of the uniaxial compression procedure, the reader is referred to Technical Data 303410-M01/78 (2). The two Phillips PR 9302 strain bridges and the Mosely Autograph 2FRA X-Y recorder referred to in that document were replaced, in the present study, by two Bruel and Kjaer Type 1526 strain indicators and a Hewlett Packard 7046B X-Y recorder. These equipment were used to measure and record the axial and transverse strains as a function of axial load. Linear variable differential transducers (LVDT's) were also utilized to provide redundant measurements of axial deformation.

## 4. DATA TREATMENT

The compressional and shear wave velocities were determined by dividing the specimen length by the wave travel time through the specimen. The dynamic properties were, then, calculated using the following equations (3):

Dynamic Shear Modulus

$$G_d = \rho V_s^2 \quad \text{Eq 1}$$

where:  $G_d$  = dynamic shear modulus  
 $V_s$  = shear wave velocity  
 $\rho$  = density

Dynamic Young's Modulus

$$E_d = \frac{\rho V_s^2 (3V_p^2 - 4V_s^2)}{V_p^2 - V_s^2} \quad \text{Eq 2}$$

where:  $E_d$  = dynamic Young's modulus  
 $V_s$  = shear wave velocity  
 $V_p$  = compressional wave velocity  
 $\rho$  = density

Poisson's Ratio (determined from velocity measurements)

$$\nu_d = \frac{V_p^2 - 2V_s^2}{2(V_p^2 - V_s^2)} \quad \text{Eq 3}$$

where:  $\nu_d$  = Poisson's ratio  
 $V_s$  = shear wave velocity  
 $V_p$  = compressional wave velocity

The stress-strain curves were computer generated using analog outputs from the strain bridges and press. Localized failure at or near the strain gauges occasionally made it necessary to utilize the lvdt outputs to determine sample strain. This is noted on the graphs where lvdt's were used. The tangent modulus of elasticity ( $E_t$ ) was calculated for each sample by determining the slope of the tangent to the axial strain curve at 50% of the failure load. The secant modulus of elasticity ( $E_s$ ) was calculated by determining the slope of the line joining the origin to the point on the axial strain curve corresponding to 50% of the failure load. The ultimate compressive strength of each sample was calculated by dividing the sample failure load by the sample's cross-sectional area. The ratio of the tangent to the transverse strain curve to the tangent to the axial strain curve, at 50% failure load, was used to determine the sample Poisson's ratio.

## 5. DATA SUMMARY

Table 2 contains the results of the ultrasonic velocity measurements including the calculated values of the dynamic shear modulus, dynamic Young's modulus as well as Poisson's ratio estimated on the basis of velocity data for each sample. Table 3 summarizes the uniaxial compression measurements which include determinations of the loading rate, uniaxial compressive strength, tangent modulus of elasticity, secant modulus of elasticity, Poisson's ratio and the predominant mode of failure for each specimen.

Figures 1 through 53 represent the circumferential and axial stress/strain curves for each sample. Also included on the figures is a summary of the sample's depth, orientation, tangent modulus and Poisson's ratio.

## 6. FAILURE CHARACTERISTICS

The predominant mode of failure was that of a double wedge or double cone configuration. These were accompanied by considerable axial splitting and slabbing. Partially formed single diagonal failure planes were apparent in several samples although the explosive nature of the failures made it impossible to measure the angles.

## 7. ACKNOWLEDGEMENTS

The author would like to acknowledge the valuable assistance of Mr. Milan Situm during this test program.

## 8. REFERENCES

1. Lang, P. Personal communication; 1985.
2. Annor, A. and Geller, L. "Dilatational velocity, Young's modulus, Poisson's ratio, uniaxial compressive strength and Brazilian tensile strength for WN1 and WN2 samples"; CANMET/MRL Technical Data 303410-M01/78; 1978.
3. Lama, R.D., Saluja, S.S. and Vutikuri, V.S. "Handbook on mechanical properties of rocks"; Volume II, Chapter 7; Trans Tech Publications.

Table 1 - Summary of sample depth, dimensions, density and orientation

| Drill hole   | Sample depth | Length | Diameter | Density              | Orientation |         |
|--------------|--------------|--------|----------|----------------------|-------------|---------|
|              | (m)          | (mm)   | (mm)     | (g/cm <sup>3</sup> ) | $\alpha$    | $\beta$ |
| 001-072-MOD1 | 1.290        | 114.49 | 44.58    | 2.63                 | 90°         | 30°     |
|              | 1.345        | 113.05 | 44.54    | 2.63                 | 90°         | 0°      |
|              | 1.395        | 111.99 | 44.54    | 2.64                 | 90°         | 60°     |
|              | 1.448        | 113.50 | 44.54    | 2.63                 | 90°         | 90°     |
|              | 1.460        | 112.70 | 44.54    | 2.63                 | 60°         | 0°      |
|              | 1.855        | 113.70 | 44.44    | 2.64                 | 0°          | -       |
|              | 2.058        | 113.64 | 44.55    | 2.63                 | 60°         | 90°     |
|              | 2.158        | 113.38 | 44.58    | 2.63                 | 30°         | 90°     |
|              | 2.283        | 113.89 | 44.48    | 2.63                 | 30°         | 0°      |
| 001-072-MOD2 | 1.497        | 112.88 | 44.54    | 2.62                 | 90°         | 0°      |
|              | 1.550        | 112.36 | 44.54    | 2.62                 | 90°         | 30°     |
|              | 1.604        | 113.48 | 44.54    | 2.62                 | 90°         | 60°     |
|              | 1.659        | 113.48 | 44.54    | 2.63                 | 90°         | 90°     |
|              | 1.667        | 113.64 | 44.58    | 2.63                 | 60°         | 0°      |
|              | 1.759        | 113.68 | 44.58    | 2.62                 | 30°         | 0°      |
|              | 2.132        | 113.70 | 44.47    | 2.62                 | 0°          | -       |
|              | 2.215        | 113.26 | 44.58    | 2.62                 | 60°         | 90°     |
|              | 2.309        | 113.04 | 44.57    | 2.64                 | 30°         | 90°     |
| 001-228-MOD1 | 3.414        | 112.79 | 44.50    | 2.63                 | 90°         | 0°      |
|              | 3.470        | 109.57 | 44.50    | 2.62                 | 90°         | 30°     |
|              | 3.525        | 112.05 | 44.49    | 2.62                 | 90°         | 60°     |
|              | 3.580        | 110.49 | 44.50    | 2.62                 | 90°         | 90°     |
|              | 3.590        | 112.18 | 44.52    | 2.62                 | 60°         | 0°      |
|              | 3.690        | 110.77 | 44.52    | 2.64                 | 60°         | 90°     |
|              | 3.695        | 113.60 | 44.52    | 2.64                 | 30°         | 0°      |
|              | 3.835        | 111.29 | 44.50    | 2.64                 | 30°         | 90°     |
|              | 4.180        | 110.27 | 44.48    | 2.63                 | 0°          | -       |

Table 1 (Cont'd)

| Drill hole   | Sample depth | Length | Diameter | Density              | Orientation |         |
|--------------|--------------|--------|----------|----------------------|-------------|---------|
|              | (m)          | (mm)   | (mm)     | (g/cm <sup>3</sup> ) | $\alpha$    | $\beta$ |
| 001-228-MOD2 | 3.488        | 108.69 | 44.50    | 2.63                 | 90°         | 0°      |
|              | 3.543        | 112.97 | 44.50    | 2.63                 | 90°         | 30°     |
|              | 3.598        | 108.05 | 44.50    | 2.64                 | 90°         | 60°     |
|              | 3.653        | 113.05 | 44.52    | 2.64                 | 90°         | 90°     |
|              | 3.674        | 112.72 | 44.50    | 2.64                 | 60°         | 0°      |
|              | 3.791        | 111.70 | 44.50    | 2.64                 | 60°         | 90°     |
|              | 3.791        | 112.27 | 44.54    | 2.64                 | 30°         | 0°      |
|              | 3.943        | 113.79 | 44.48    | 2.64                 | 30°         | 90°     |
|              | 4.342        | 112.71 | 44.50    | 2.64                 | 0°          | -       |
| 001-275-MOD1 | 1.850        | 113.87 | 44.49    | 2.64                 | 90°         | 0°      |
|              | 1.905        | 113.40 | 44.49    | 2.63                 | 90°         | 30°     |
|              | 1.960        | 111.27 | 44.48    | 2.64                 | 90°         | 60°     |
|              | 2.015        | 110.40 | 44.49    | 2.63                 | 90°         | 90°     |
|              | 2.033        | 113.41 | 44.52    | 2.63                 | 60°         | 0°      |
|              | 2.144        | 110.39 | 44.54    | 2.63                 | 30°         | 0°      |
|              | 2.146        | 111.91 | 44.52    | 2.63                 | 60°         | 90°     |
|              | 2.296        | 110.68 | 44.52    | 2.62                 | 30°         | 90°     |
|              | 2.715        | 112.20 | 44.46    | 2.63                 | 0°          | -       |
| 001-275-MOD2 | 1.852        | 112.82 | 44.50    | 2.64                 | 90°         | 0°      |
|              | 1.907        | 112.90 | 44.51    | 2.64                 | 90°         | 30°     |
|              | 1.962        | 112.76 | 44.50    | 2.64                 | 90°         | 60°     |
|              | 2.032        | 112.41 | 44.54    | 2.62                 | 60°         | 0°      |
|              | 2.145        | 112.70 | 44.56    | 2.63                 | 30°         | 0°      |
|              | 2.147        | 113.00 | 44.54    | 2.64                 | 60°         | 90°     |
|              | 2.294        | 113.86 | 44.55    | 2.62                 | 30°         | 90°     |
|              | 2.674        | 112.56 | 44.46    | 2.63                 | 0°          | -       |

Table 2 - Summary of ultrasonic velocity properties

| Drill hole   | Sample depth (m) | P-wave velocity (km/s) | S-wave velocity (km/s) | Dynamic shear modulus, G (GPa) | Dynamic Young's modulus, $E_d$ (GPa) | Dynamic Poisson's ratio |
|--------------|------------------|------------------------|------------------------|--------------------------------|--------------------------------------|-------------------------|
| 001-072-MOD1 | 1.290            | 5.14                   | 3.48                   | 30.82                          | 66.33                                | 0.08                    |
|              | 1.345            | 5.58                   | 3.65                   | 33.91                          | 76.34                                | 0.13                    |
|              | 1.395            | 4.34                   | 3.24                   | 26.71                          | 46.67                                | -0.13                   |
|              | 1.448            | 4.15                   | 2.89                   | 21.31                          | 43.73                                | 0.03                    |
|              | 1.460            | 5.54                   | 3.61                   | 33.07                          | 74.86                                | 0.13                    |
|              | 1.855            | 5.16                   | 3.44                   | 30.02                          | 66.11                                | 0.10                    |
|              | 2.058            | 4.26                   | 2.62                   | 17.46                          | 41.76                                | 0.20                    |
|              | 2.158            | 4.93                   | 3.32                   | 27.90                          | 60.66                                | 0.09                    |
|              | 2.283            | 5.42                   | 3.57                   | 32.37                          | 72.36                                | 0.12                    |
|              |                  |                        |                        |                                |                                      |                         |
| 001-072-MOD2 | 1.497            | 5.72                   | 3.73                   | 35.15                          | 79.48                                | 0.13                    |
|              | 1.550            | 5.23                   | 3.48                   | 30.76                          | 67.66                                | 0.10                    |
|              | 1.604            | 4.88                   | 3.24                   | 26.57                          | 58.82                                | 0.11                    |
|              | 1.659            | 4.82                   | 3.31                   | 27.89                          | 58.65                                | 0.05                    |
|              | 1.667            | 5.36                   | 3.59                   | 32.68                          | 71.45                                | 0.09                    |
|              | 1.759            | 4.71                   | 2.93                   | 21.81                          | 51.57                                | 0.18                    |
|              | 2.132            | 4.08                   | 2.74                   | 19.05                          | 41.38                                | 0.09                    |
|              | 2.215            | 4.98                   | 3.35                   | 28.36                          | 61.71                                | 0.09                    |
|              | 2.309            | 4.87                   | 3.19                   | 25.89                          | 58.28                                | 0.12                    |
|              |                  |                        |                        |                                |                                      |                         |

Table 2 (cont'd)

| Drill hole   | Sample depth (m)        | P-wave velocity (km/s) | S-wave velocity (km/s) | Dynamic shear modulus, G (GPa) | Dynamic Young's modulus, $E_d$ (GPa) | Dynamic Poisson's ratio |
|--------------|-------------------------|------------------------|------------------------|--------------------------------|--------------------------------------|-------------------------|
| 001-228-MOD1 | 3.414                   | 5.85                   | 3.82                   | 36.99                          | 83.54                                | 0.13                    |
|              | 3.470                   | 5.53                   | 3.60                   | 32.88                          | 74.41                                | 0.13                    |
|              | 3.525                   | 5.20                   | 3.40                   | 29.27                          | 65.92                                | 0.13                    |
|              | 3.580                   | 5.10                   | 3.32                   | 27.82                          | 63.10                                | 0.13                    |
|              | 3.590                   | 5.51                   | 3.57                   | 32.31                          | 73.53                                | 0.14                    |
|              | 3.690                   | 5.16                   | 3.48                   | 31.04                          | 67.22                                | 0.08                    |
|              | 3.695                   | 5.15                   | 3.59                   | 32.92                          | 67.72                                | 0.03                    |
|              | 3.835                   | 5.16                   | 3.39                   | 29.32                          | 65.82                                | 0.12                    |
|              | 4.180                   | 5.12                   | 3.51                   | 31.37                          | 66.17                                | 0.06                    |
|              |                         |                        |                        |                                |                                      |                         |
|              |                         |                        |                        |                                |                                      |                         |
| 001-228-MOD2 | 3.488                   | 5.69                   | 3.85                   | 37.64                          | 81.23                                | 0.08                    |
|              | 3.543                   | 5.81                   | 3.86                   | 37.81                          | 83.65                                | 0.11                    |
|              | 3.598                   | 5.61                   | 3.78                   | 36.37                          | 78.97                                | 0.09                    |
|              | 3.653                   | 5.42                   | 3.75                   | 35.77                          | 74.53                                | 0.04                    |
|              | 3.674                   | 5.68                   | 3.87                   | 38.13                          | 81.41                                | 0.07                    |
|              | 3.791( $\pi=60^\circ$ ) | 5.41                   | 3.70                   | 34.86                          | 73.97                                | 0.06                    |
|              | 3.791( $\pi=30^\circ$ ) | 5.45                   | 3.79                   | 36.65                          | 75.53                                | 0.03                    |
|              | 3.943                   | 5.30                   | 3.69                   | 34.77                          | 71.56                                | 0.03                    |
|              | 4.342                   | 5.43                   | 3.76                   | 36.29                          | 74.93                                | 0.03                    |
|              |                         |                        |                        |                                |                                      |                         |
|              |                         |                        |                        |                                |                                      |                         |

Table 2 (cont'd)

| Drill hole   | Sample<br>depth<br>(m) | P-wave<br>velocity<br>(km/s) | S-wave<br>velocity<br>(km/s) | Dynamic shear<br>modulus, G<br>(GPa) | Dynamic Young's<br>modulus, $E_d$<br>(GPa) | Dynamic Poisson's<br>ratio |
|--------------|------------------------|------------------------------|------------------------------|--------------------------------------|--------------------------------------------|----------------------------|
| 001-275-MOD1 | 1.850                  | 5.35                         | 3.58                         | 32.64                                | 71.35                                      | 0.09                       |
|              | 1.905                  | 5.37                         | 3.50                         | 31.18                                | 70.44                                      | 0.13                       |
|              | 1.960                  | 5.16                         | 3.47                         | 30.61                                | 66.72                                      | 0.09                       |
|              | 2.015                  | 4.93                         | 3.81                         | 36.89                                | 55.64                                      | -0.25                      |
|              | 2.033                  | 5.16                         | 3.47                         | 30.59                                | 66.34                                      | 0.08                       |
|              | 2.144                  | 4.86                         | 3.26                         | 26.64                                | 57.98                                      | 0.09                       |
|              | 2.146                  | 4.70                         | 3.12                         | 25.07                                | 55.36                                      | 0.10                       |
|              | 2.296                  | 4.70                         | 3.63                         | 33.48                                | 50.60                                      | -0.24                      |
|              | 2.715                  | 4.63                         | 3.20                         | 26.03                                | 54.18                                      | 0.04                       |
| 001-228-MOD2 | 1.852                  | 5.27                         | 3.56                         | 32.44                                | 70.00                                      | 0.08                       |
|              | 1.907                  | 5.39                         | 3.60                         | 33.09                                | 72.57                                      | 0.10                       |
|              | 1.962                  | 5.18                         | 3.49                         | 31.05                                | 67.39                                      | 0.09                       |
|              | 2.032                  | 5.25                         | 3.50                         | 31.06                                | 68.34                                      | 0.10                       |
|              | 2.145                  | 5.25                         | 3.49                         | 31.04                                | 68.49                                      | 0.10                       |
|              | 2.147                  | 4.88                         | 3.37                         | 28.96                                | 60.42                                      | 0.04                       |
|              | 2.294                  | 5.02                         | 3.97                         | 39.88                                | 53.00                                      | -0.33                      |
|              | 2.674                  | 5.00                         | 3.36                         | 28.74                                | 62.46                                      | 0.09                       |

Table 3 - Summary of uniaxial compression properties

| Drill hole   | Sample depth (m) | Loading rate (MPa/s) | Uniaxial compressive strength (MPa) | Tangent modulus of elasticity (GPa) | Secant modulus of elasticity (GPa) | Poisson's ratio | Predominant failure characteristic |
|--------------|------------------|----------------------|-------------------------------------|-------------------------------------|------------------------------------|-----------------|------------------------------------|
| 001-072-MOD1 | 1.290            | 1.20                 | 174                                 | 65.08                               | 55.49                              | 0.26            | single diagonal failure plane      |
|              | 1.345            | 0.90                 | 194                                 | 71.53                               | 68.31                              | 0.29            | single diagonal failure plane      |
|              | 1.395            | 0.56                 | 142                                 | 68.63                               | 61.76                              | 0.22            | single diagonal failure plane      |
|              | 1.448            | 0.76                 | 191                                 | 64.04                               | 47.87                              | 0.20            | double wedge                       |
|              | 1.460            | 0.81                 | 151                                 | 64.90                               | 66.30                              | 0.17            | single diagonal failure plane      |
|              | 1.855            | 1.02                 | 196                                 | 66.48                               | 58.49                              | 0.22            | double wedge                       |
|              | 2.058            | 0.94                 | 179                                 | 65.65                               | 54.56                              | 0.27            | double cone                        |
|              | 2.158            | 0.59                 | 134                                 | 65.56                               | 54.86                              | 0.21            | bottom wedge                       |
|              | 2.283            | 0.93                 | 169                                 | 66.21                               | 64.02                              | 0.23            | axial splitting                    |
|              |                  |                      |                                     |                                     |                                    |                 |                                    |
| 206-072-MOD2 | 1.497            | 0.68                 | 166                                 | 68.92                               | 66.08                              | 0.25            | double cone                        |
|              | 1.550            | 0.72                 | 144                                 | 65.92                               | 61.41                              | 0.26            | bottom wedge                       |
|              | 1.604            | 0.87                 | 171                                 | 64.60                               | 54.24                              | 0.22            | bottom cone                        |
|              | 1.659            | 0.88                 | 198                                 | 68.46                               | 58.89                              | 0.30            | bottom cone                        |
|              | 1.667            | 0.97                 | 166                                 | 73.29                               | 66.01                              | 0.29            | bottom wedge                       |
|              | 1.759            | 0.80                 | 172                                 | 68.32                               | 54.70                              | 0.33            | axial splitting                    |
|              | 2.132            | 0.79                 | 194                                 | 65.88                               | 50.27                              | 0.21            | double cone                        |
|              | 2.215            | 0.82                 | 176                                 | 65.35                               | 59.73                              | 0.26            | bottom wedge                       |
|              | 2.309            | 0.96                 | 185                                 | 75.33                               | 65.41                              | 0.26            | top wedge                          |
|              |                  |                      |                                     |                                     |                                    |                 |                                    |
| #01-228-MOD1 | 3.414            | 0.98                 | 194                                 | 70.32                               | 69.69                              | 0.24            | double cone                        |
|              | 3.470            | 0.82                 | 179                                 | 58.75                               | 57.71                              | 0.18            | bottom cone                        |
|              | 3.525            | 1.10                 | 179                                 | 70.61                               | 65.10                              | 0.26            | double cone                        |
|              | 3.580            | 0.81                 | 155                                 | 65.33                               | 57.46                              | 0.29            | bottom wedge                       |
|              | 3.590            | 0.73                 | 145                                 | 65.87                               | 62.96                              | 0.22            | bottom wedge                       |
|              | 3.690            | 0.86                 | 177                                 | 69.56                               | 60.07                              | 0.24            | top wedge                          |
|              | 3.695            | 0.69                 | 204                                 | 70.42                               | 64.44                              | 0.22            | single diagonal failure plane      |
|              | 3.835            | 0.87                 | 204                                 | 66.61                               | 65.03                              | 0.26            | double cone                        |
|              | 4.180            | 0.80                 | 198                                 | 69.89                               | 63.79                              | 0.27            | top cone                           |
|              |                  |                      |                                     |                                     |                                    |                 |                                    |

Table 3 (Cont'd)

| Drill hole   | Sample depth (m)           | Loading rate (MPa/s) | Uniaxial compressive strength (MPa) | Tangent modulus of elasticity (GPa) | Secant modulus of elasticity (GPa) | Poisson's ratio | Predominant failure characteristic |
|--------------|----------------------------|----------------------|-------------------------------------|-------------------------------------|------------------------------------|-----------------|------------------------------------|
| 001-228-MOD2 | 3.488                      | 1.16                 | 228                                 | 73.46                               | 71.96                              | 0.25            | double cone                        |
|              | 3.543                      | 1.02                 | 210                                 | 72.25                               | 71.02                              | 0.23            | bottom wedge                       |
|              | 3.598                      | 0.86                 | 194                                 | 70.14                               | 69.78                              | 0.21            | double wedge                       |
|              | 3.653                      | 0.92                 | 222                                 | 70.91                               | 67.43                              | 0.23            | bottom cone                        |
|              | 3.674                      | 0.90                 | 215                                 | 77.25                               | 74.97                              | 0.26            | double wedge                       |
|              | 3.791( $\alpha=60^\circ$ ) | 0.96                 | 201                                 | 69.54                               | 64.35                              | 0.20            | double cone                        |
|              | 3.791( $\alpha=30^\circ$ ) | 0.95                 | 217                                 | 73.54                               | 70.34                              | 0.25            | double cone                        |
|              | 3.943                      | 0.88                 | 219                                 | 69.63                               | 65.28                              | 0.24            | double cone                        |
|              | 4.432                      | 0.92                 | 210                                 | 69.91                               | 65.90                              | 0.25            | bottom wedge                       |
|              |                            |                      |                                     |                                     |                                    |                 |                                    |
| 001-275-MOD1 | 1.850                      | 1.11                 | 167                                 | 68.50                               | 64.12                              | 0.25            | bottom wedge                       |
|              | 1.905                      | 0.98                 | 192                                 | 68.44                               | 63.72                              | 0.28            | double wedge                       |
|              | 1.960                      | 0.99                 | 180                                 | 77.76                               | 68.59                              | 0.25            | bottom wedge                       |
|              | 2.015                      | 1.08                 | 174                                 | 70.16                               | 61.52                              | 0.27            | bottom wedge                       |
|              | 2.033                      | 0.98                 | 192                                 | 74.70                               | 69.03                              | 0.30            | bottom wedge                       |
|              | 2.144                      | 0.98                 | 146                                 | 66.36                               | 56.05                              | 0.28            | single diagonal failure plane      |
|              | 2.146                      | 0.88                 | 202                                 | 71.01                               | 64.66                              | 0.25            | double cone                        |
|              | 2.296                      | 1.02                 | 188                                 | 61.86                               | 58.79                              | 0.19            | axial splitting                    |
|              | 2.715                      | 0.86                 | 206                                 | 66.22                               | 56.96                              | 0.21            | double wedge                       |
|              |                            |                      |                                     |                                     |                                    |                 |                                    |
| 206-075-MOD2 | 1.852                      | 0.81                 | 172                                 | 71.19                               | 64.73                              | 0.23            | double cone                        |
|              | 1.907                      | 0.91                 | 166                                 | 70.09                               | 64.05                              | 0.31            | double cone                        |
|              | 1.962                      | 0.85                 | 158                                 | 77.41                               | 57.50                              | 0.23            | failed along discontinuity         |
|              | 2.032                      | 0.80                 | 168                                 | 74.26                               | 64.35                              | 0.29            | double cone                        |
|              | 2.145                      | 0.90                 | 162                                 | 74.21                               | 66.68                              | 0.26            | double cone                        |
|              | 2.147                      | 0.79                 | 167                                 | 68.12                               | 60.16                              | 0.23            | double cone                        |
|              | 2.294                      | 0.66                 | 186                                 | 65.08                               | 60.03                              | 0.21            | double cone                        |
|              | 2.674                      | 0.80                 | 186                                 | 67.79                               | 60.43                              | 0.27            | double cone                        |

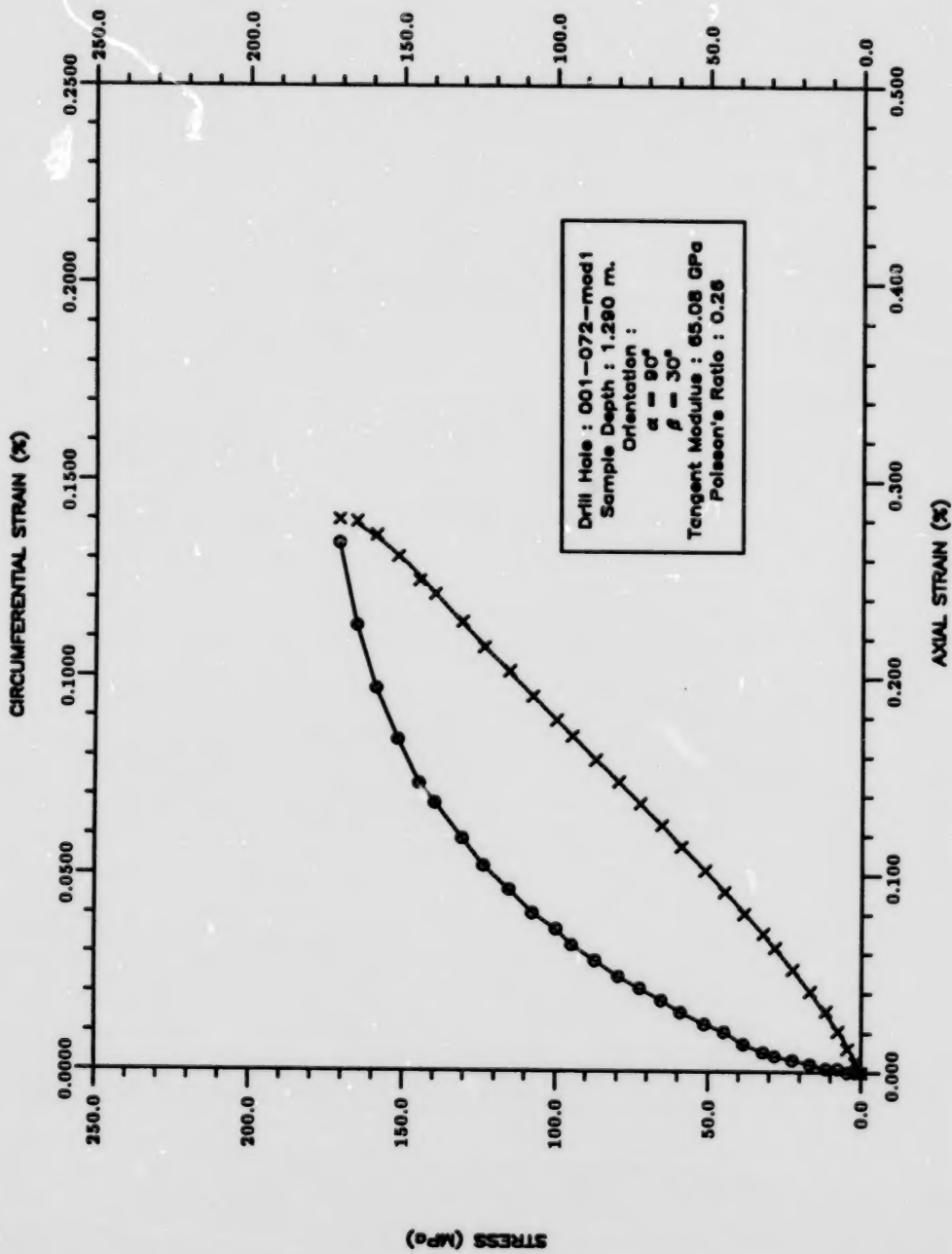


Fig. 1 : Axial and circumferential stress/strain curves for anisotropy test specimens.

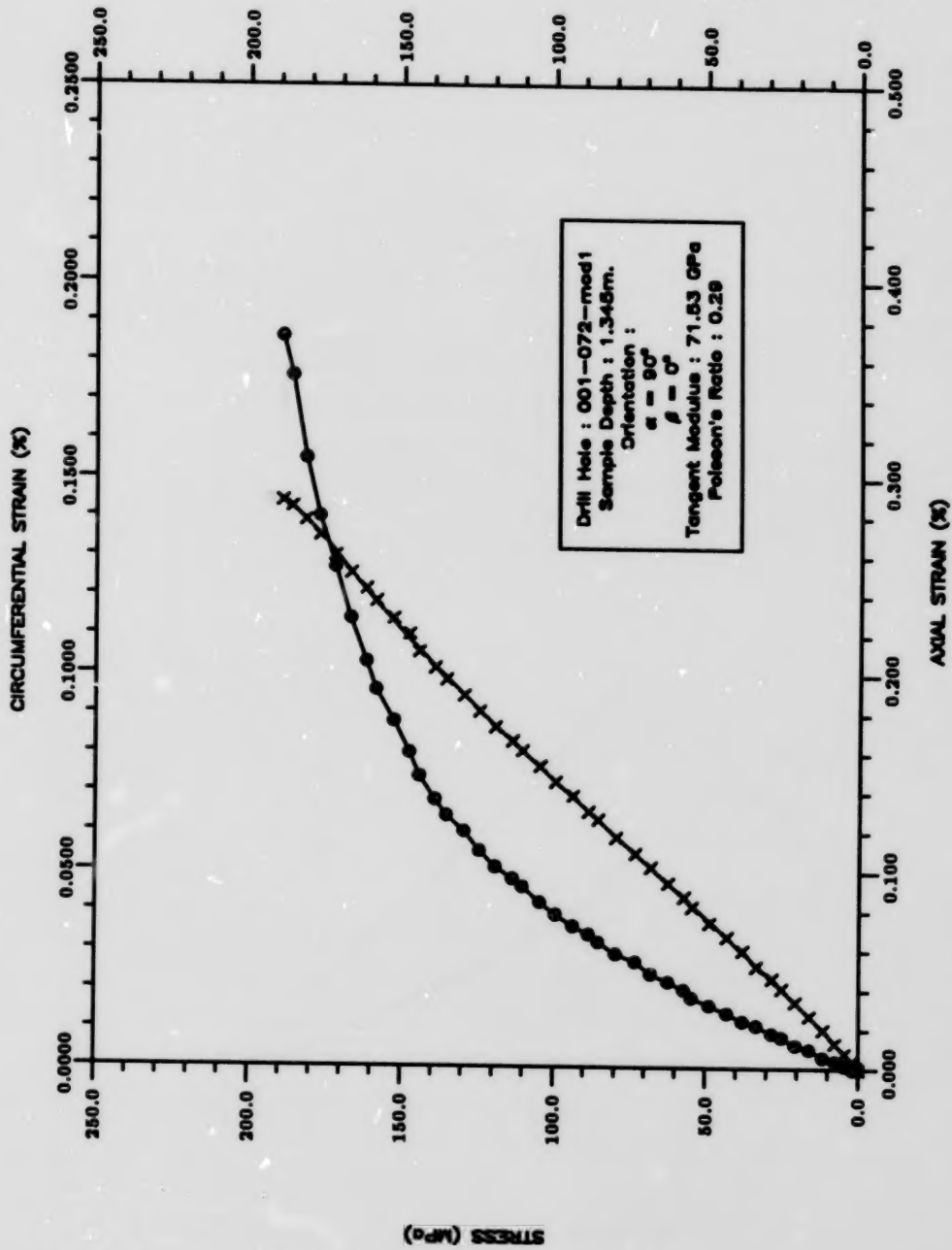


Fig. 2: Axial and circumferential stress/strain curves for anisotropy test specimens.

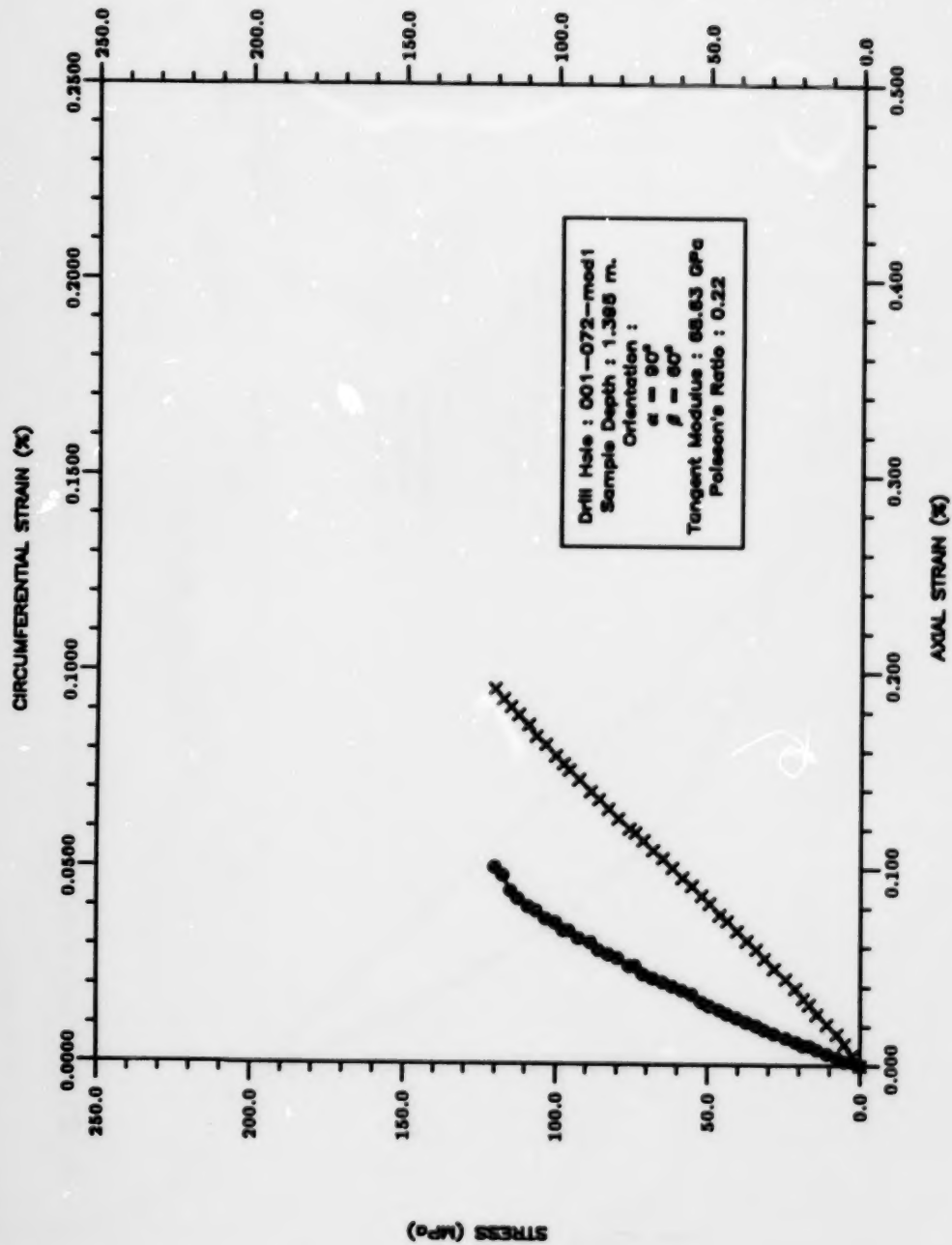


Fig. 3: Axial and circumferential stress/strain curves for anisotropy test specimens.

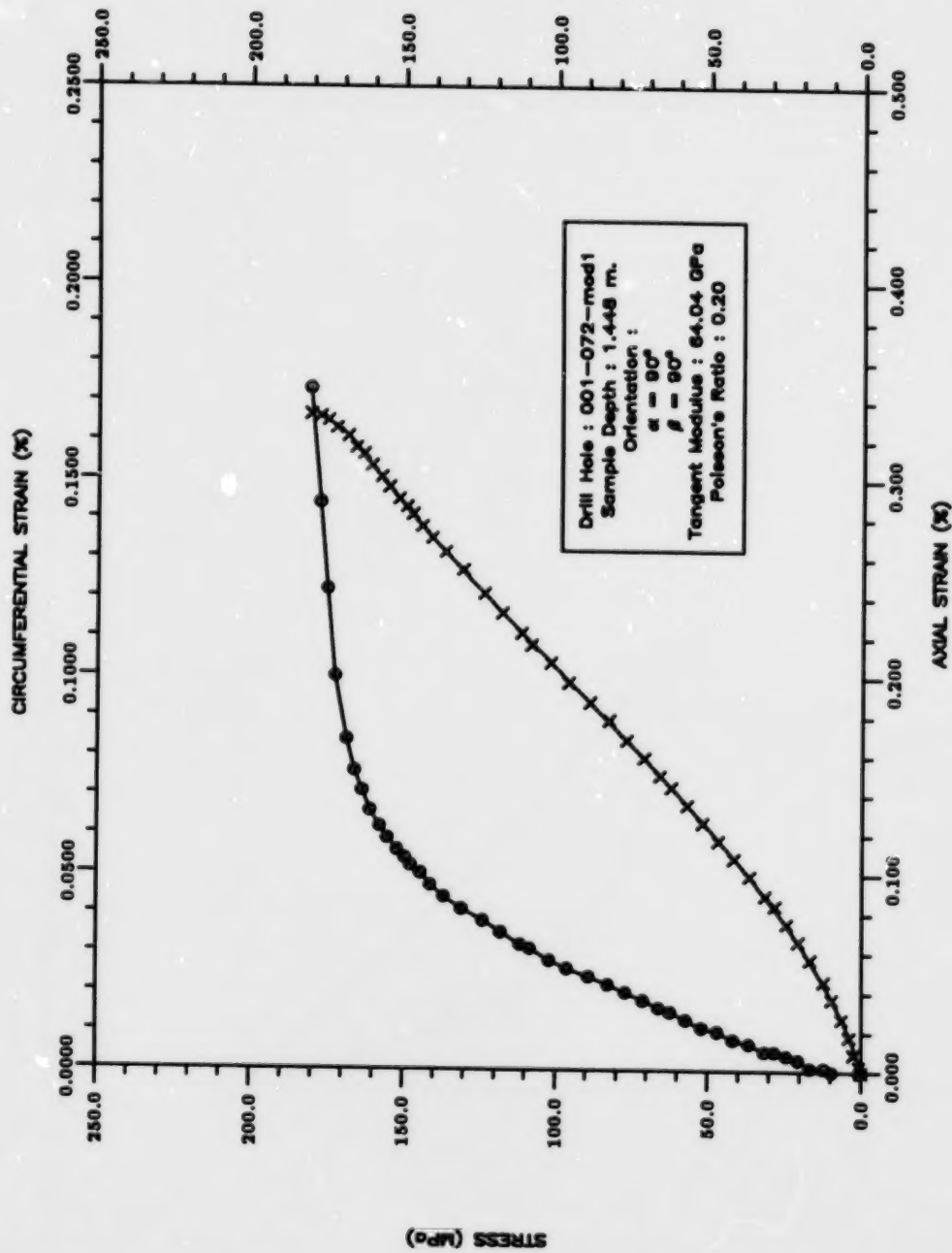


Fig. 4: Axial and circumferential stress/strain curves for anisotropy test specimens.

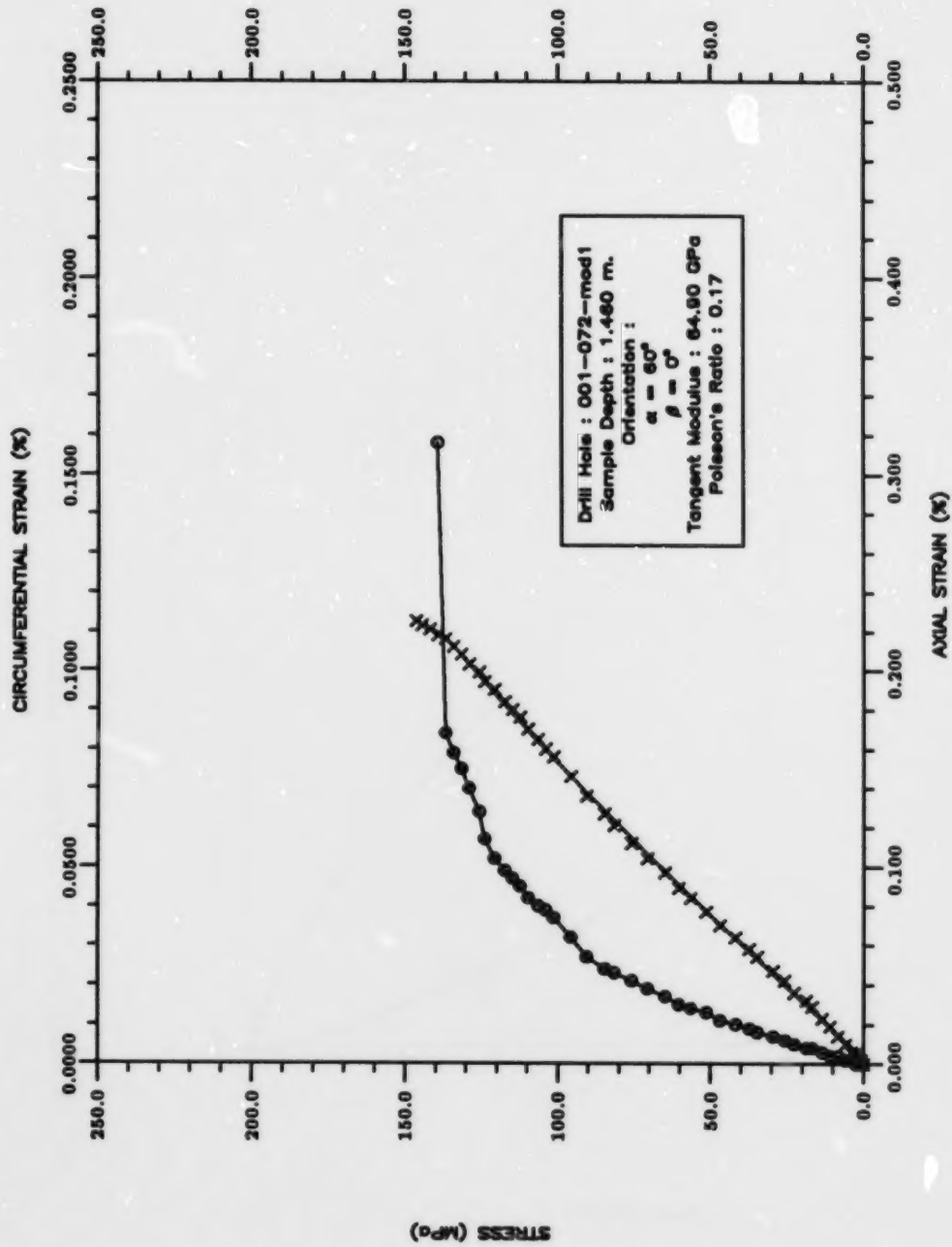


Fig. 5: Axial and circumferential stress/strain curves for anisotropy test specimens.

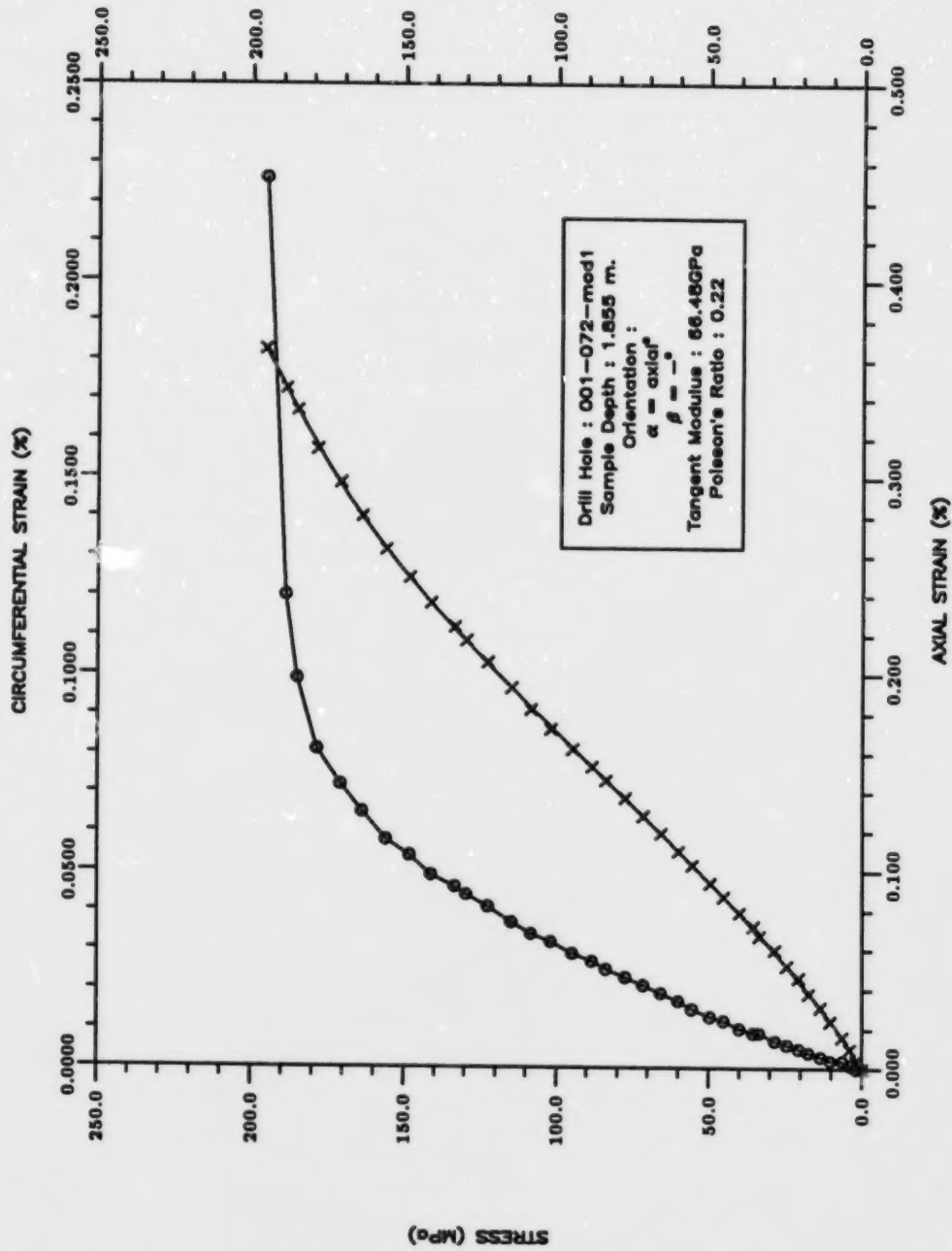


Fig. 6: Axial and circumferential stress/strain curves for anisotropy test specimens.

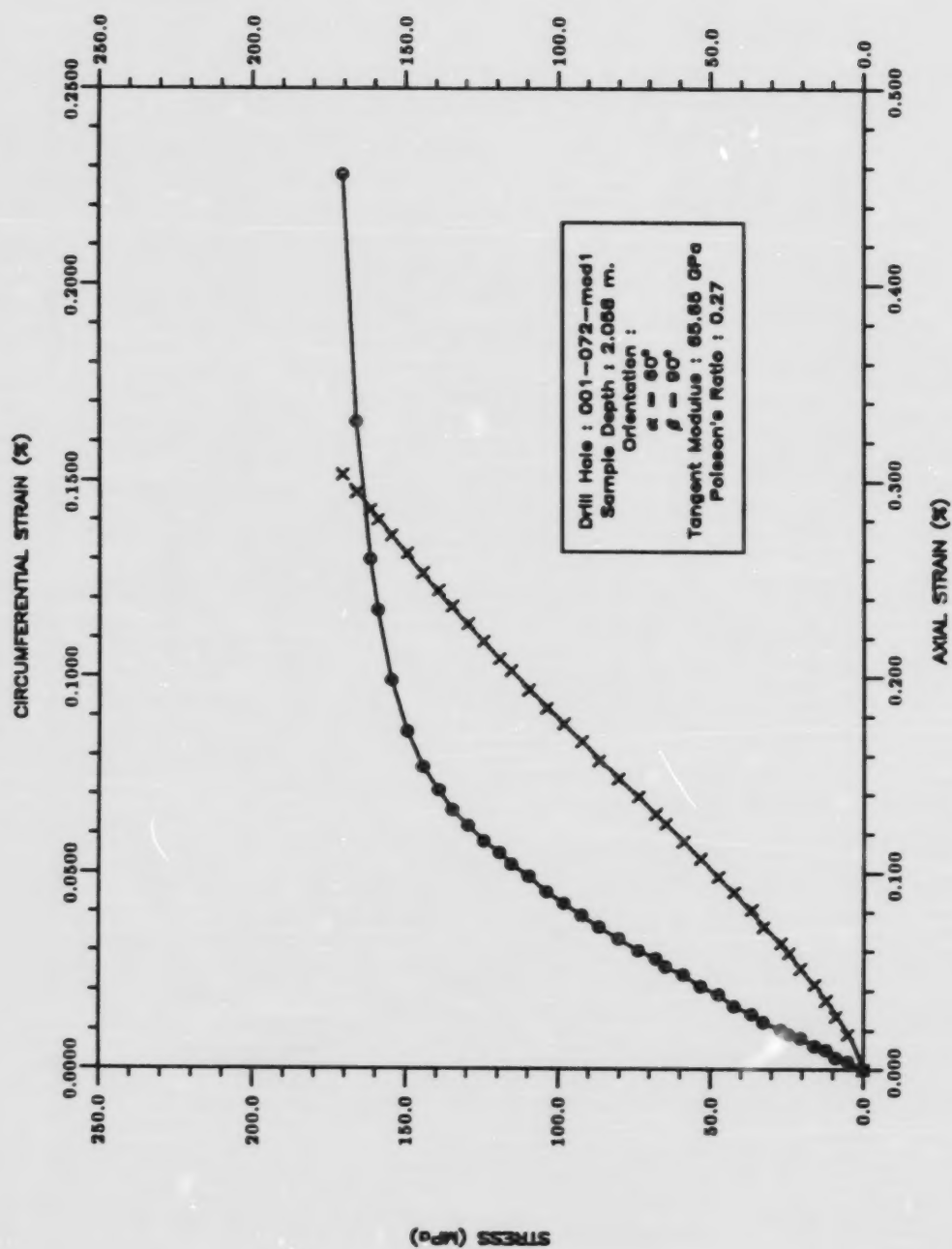


Fig. 7: Axial and circumferential stress/strain curves for anisotropy test specimens.

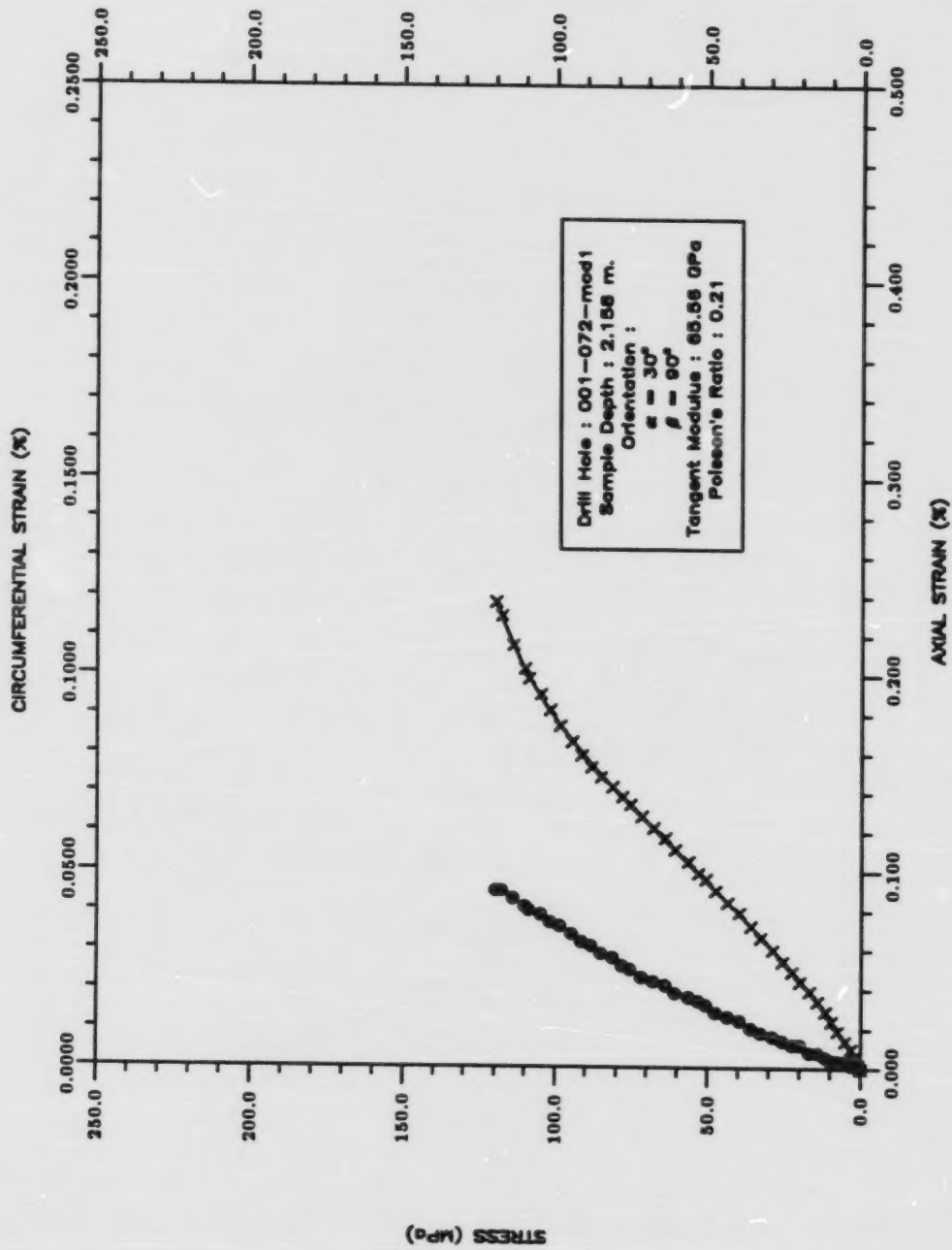


Fig. 8: Axial and circumferential stress/strain curves for anisotropy test specimens.

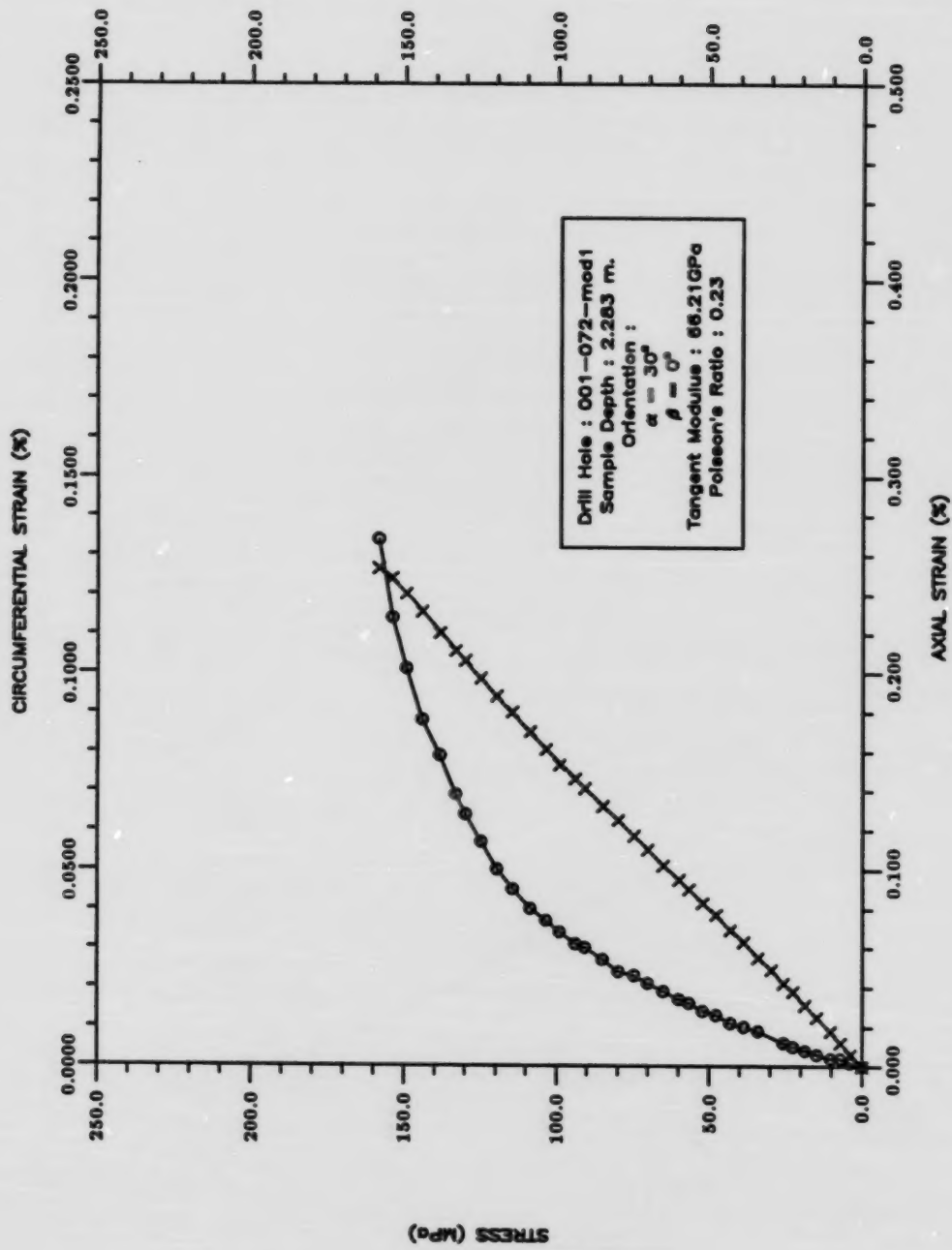


Fig. 9: Axial and circumferential stress/strain curves for anisotropy test specimens.

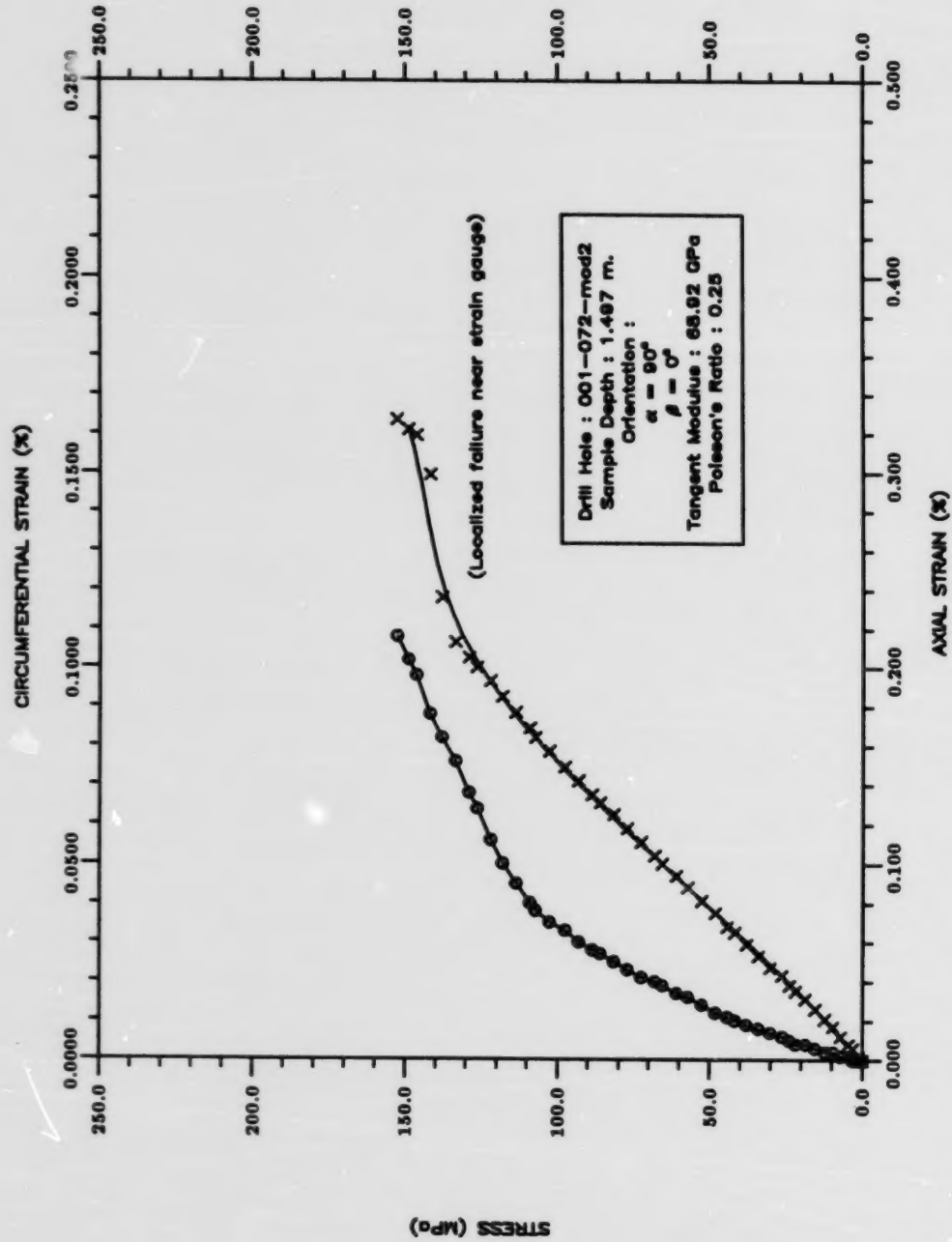


Fig. 10: Axial and circumferential stress/strain curves for anisotropy test specimens.

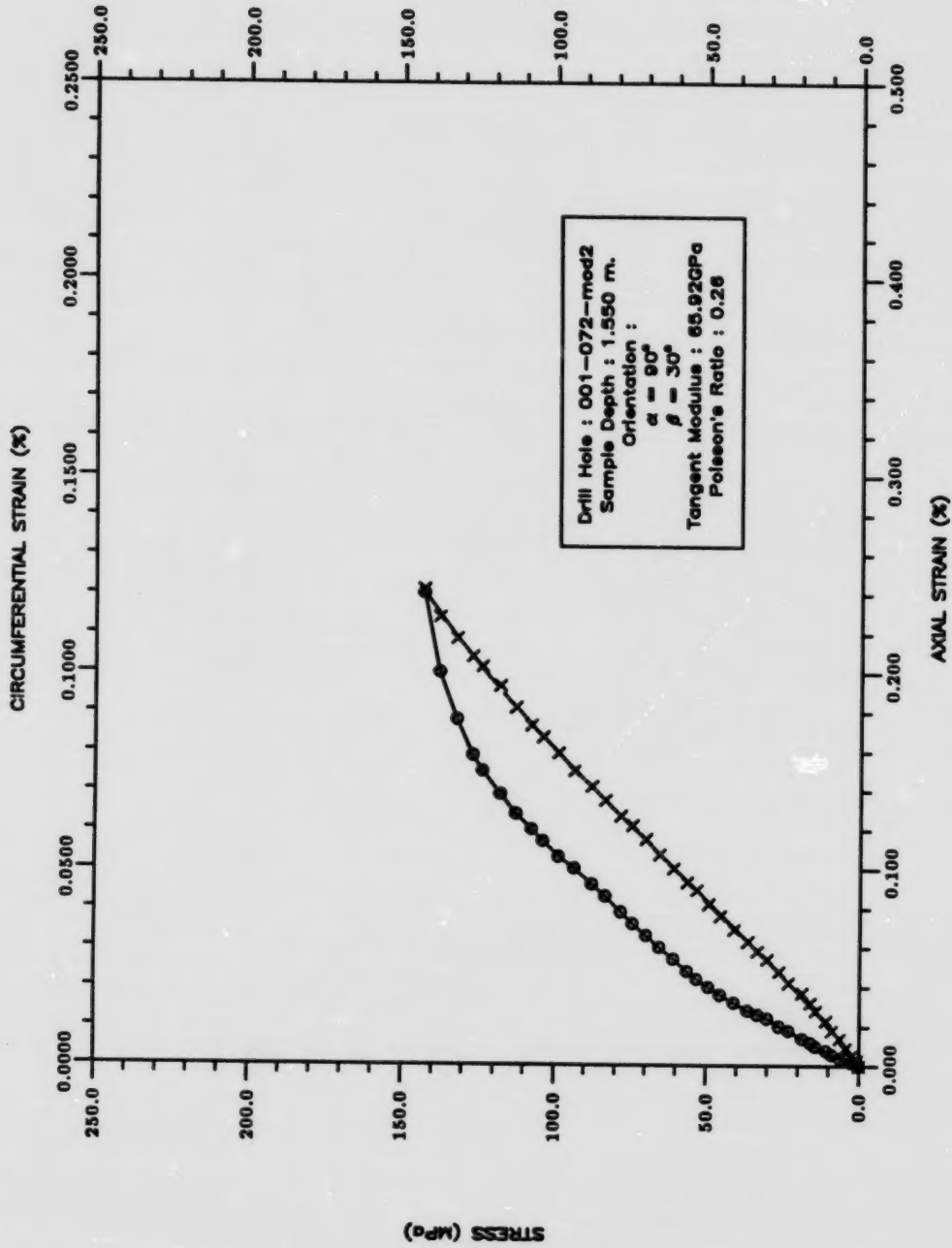


Fig. 11: Axial and circumferential stress/strain curves for anisotropy test specimens.

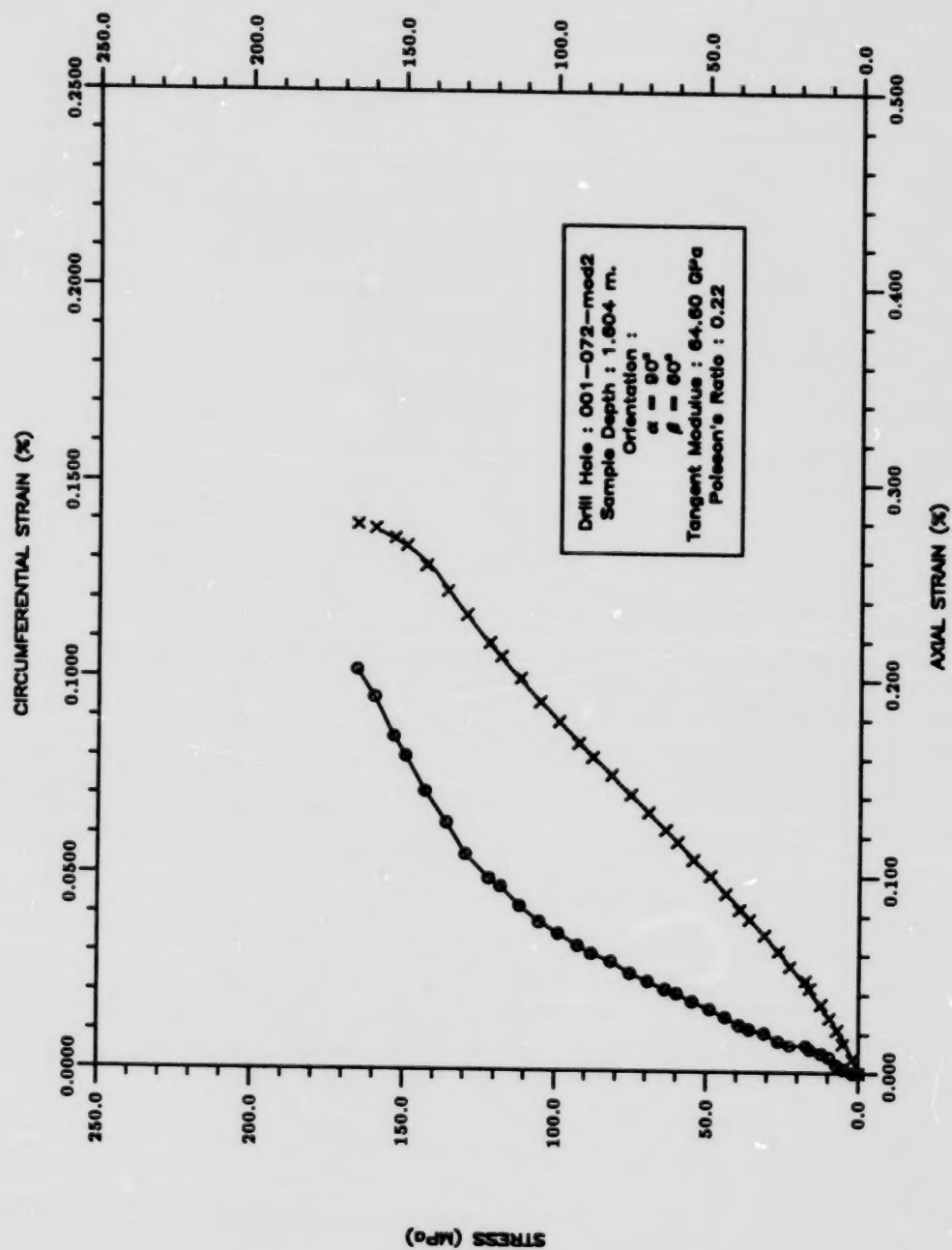


Fig. 12: Axial and circumferential stress/strain curves for anisotropy test specimens.

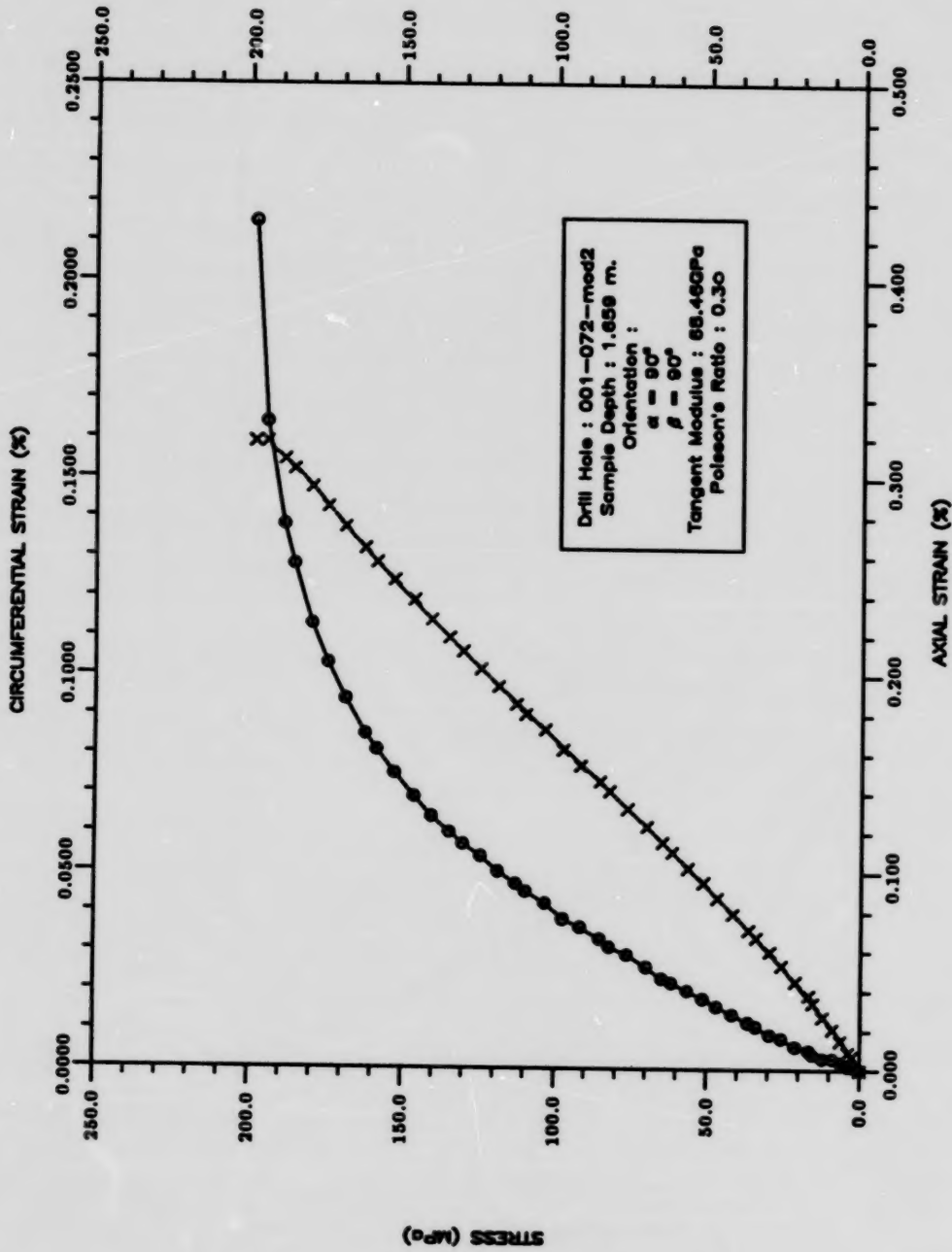


Fig. 13: Axial and circumferential stress/strain curves for anisotropy test specimens.

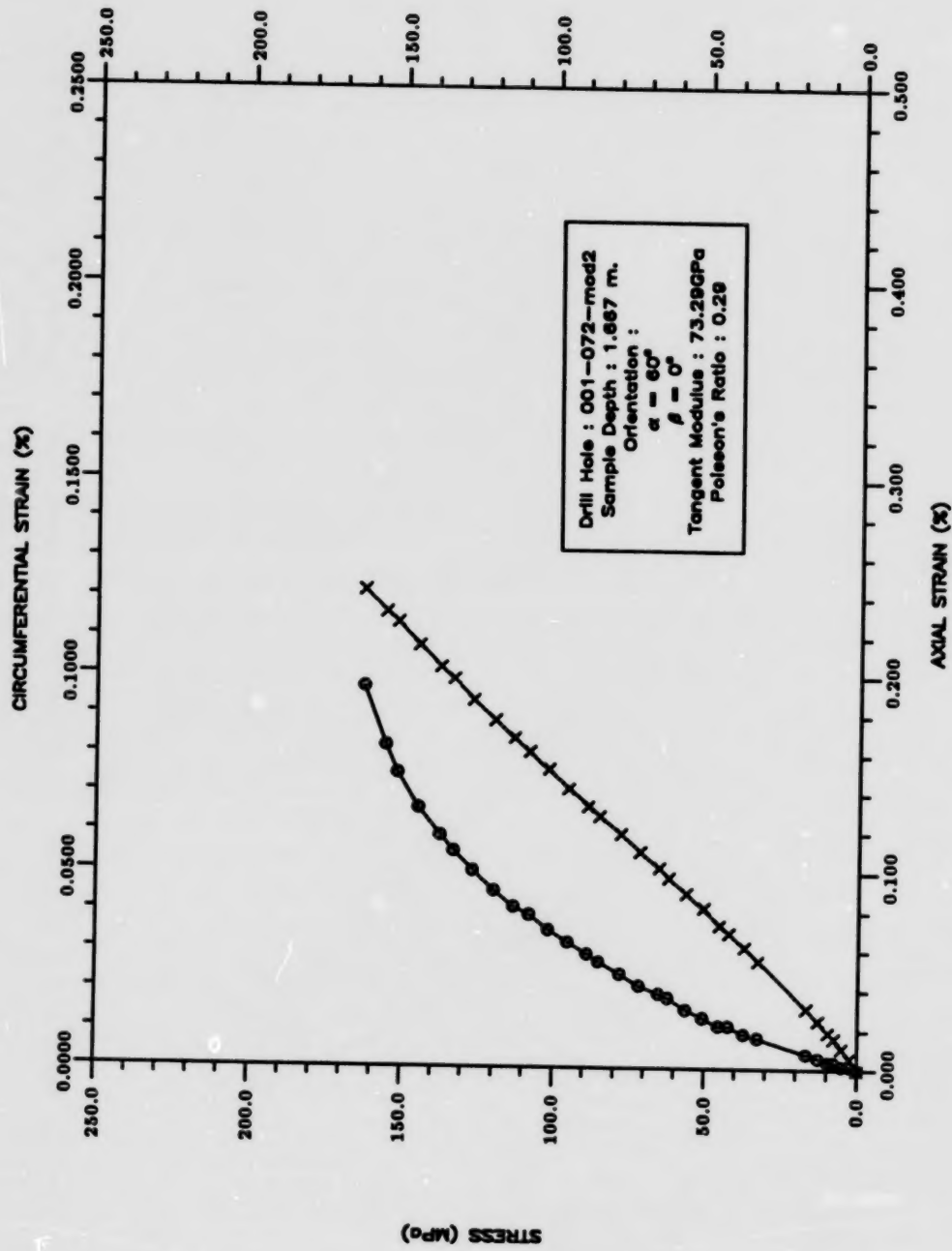


Fig. 14: Axial and circumferential stress/strain curves for anisotropy test specimens.

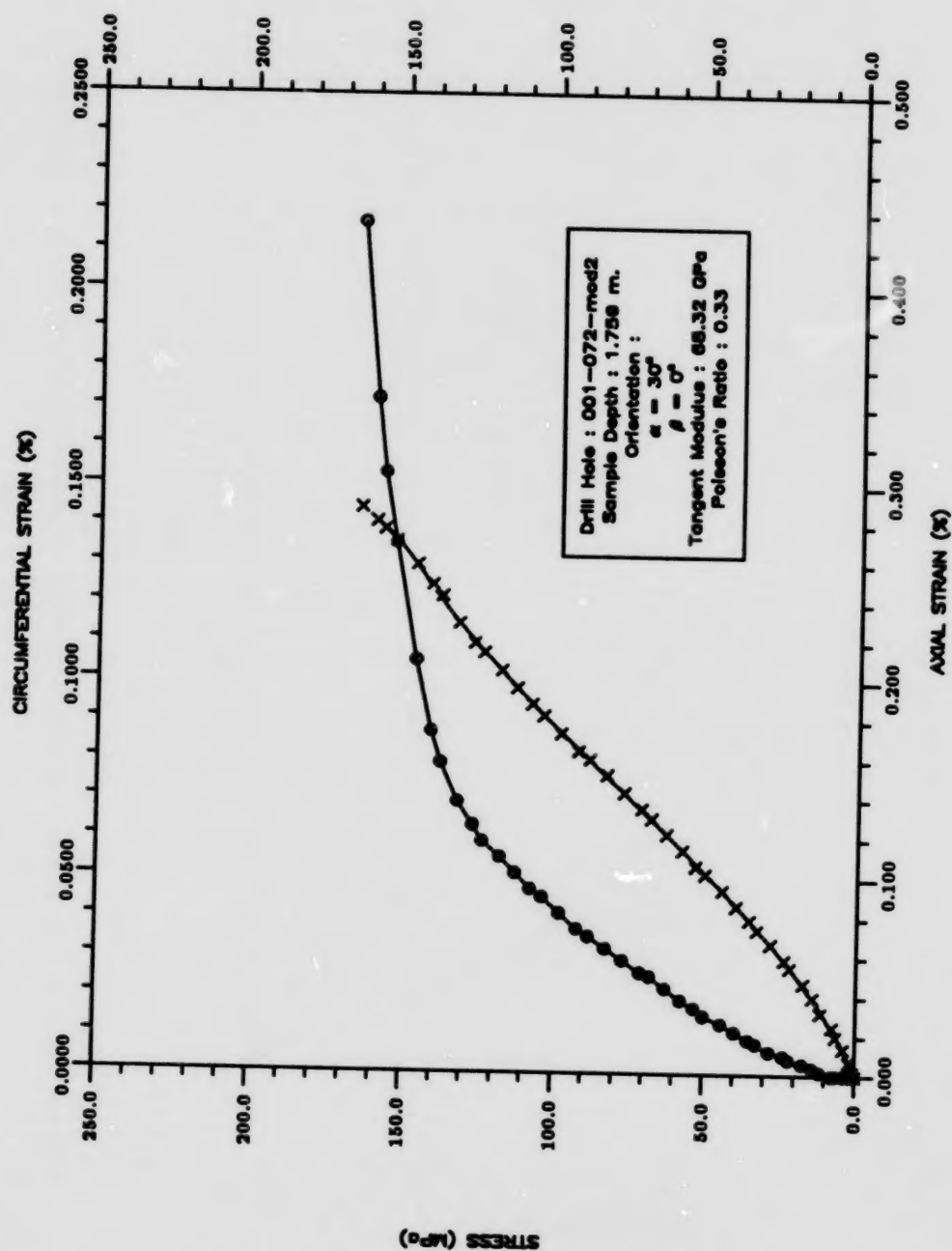


Fig. 15: Axial and circumferential stress/strain curves for anisotropy test specimens.

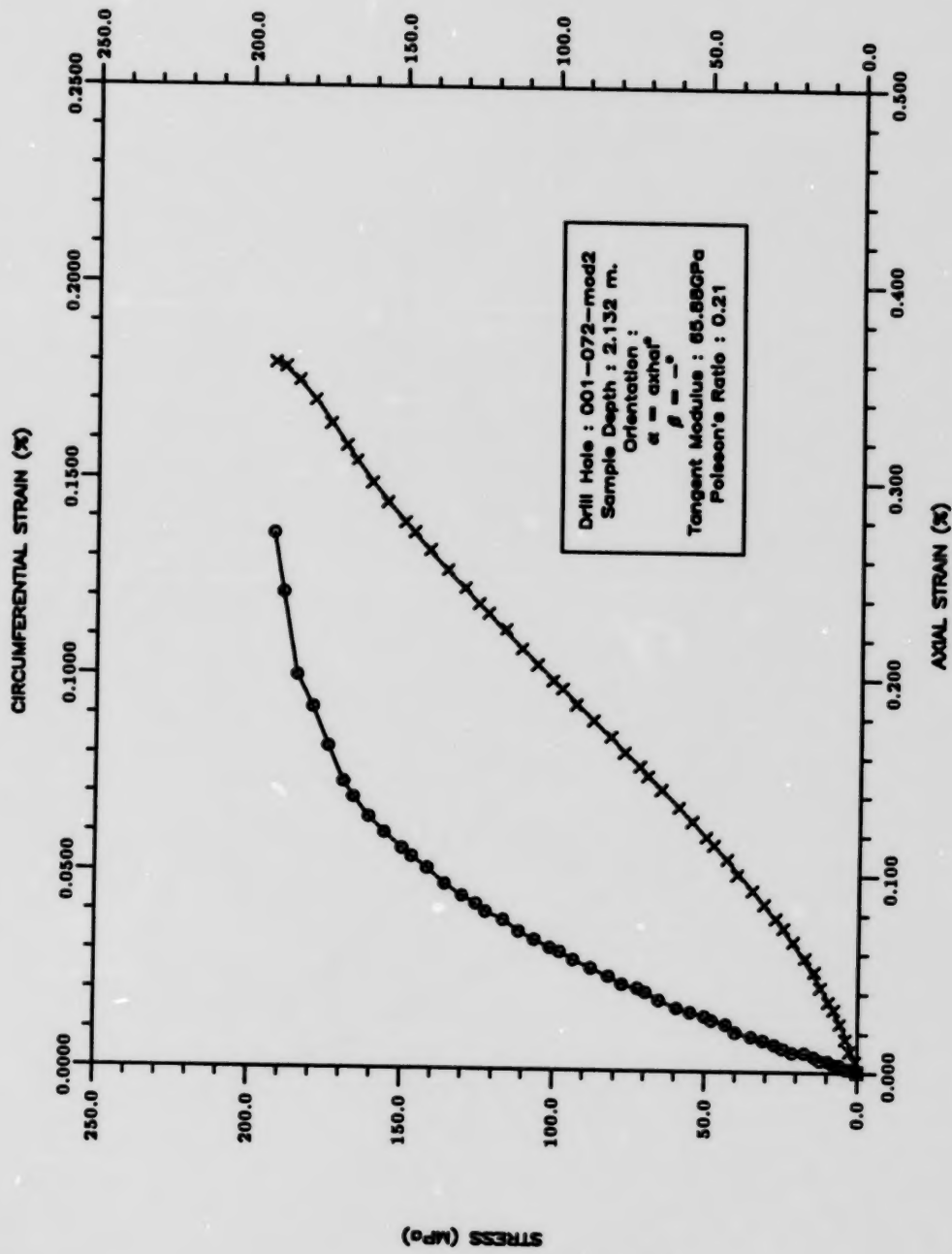


Fig. 16: Axial and circumferential stress/strain curves for anisotropy test specimens.

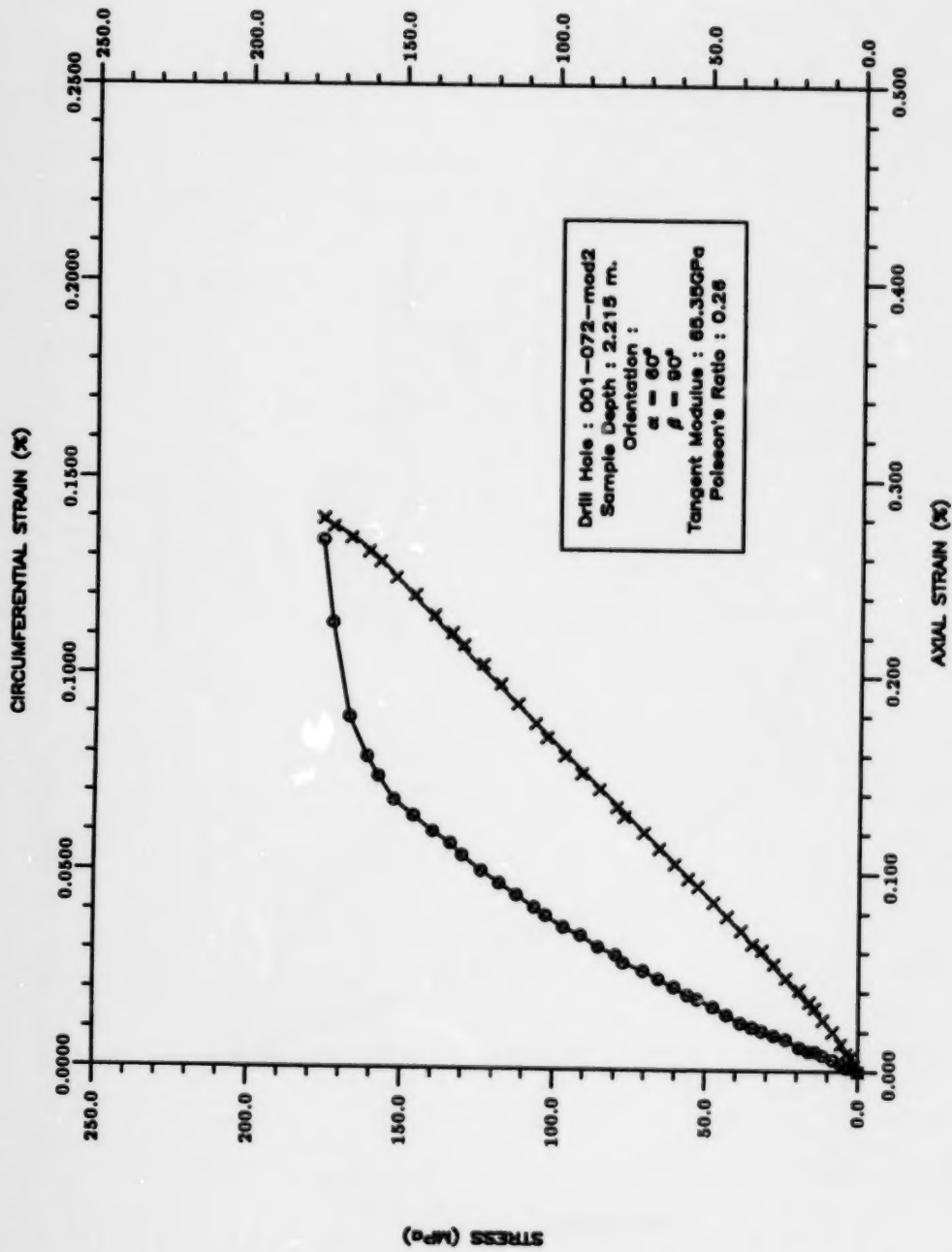


Fig. 17: Axial and circumferential stress/strain curves for anisotropy test specimens.

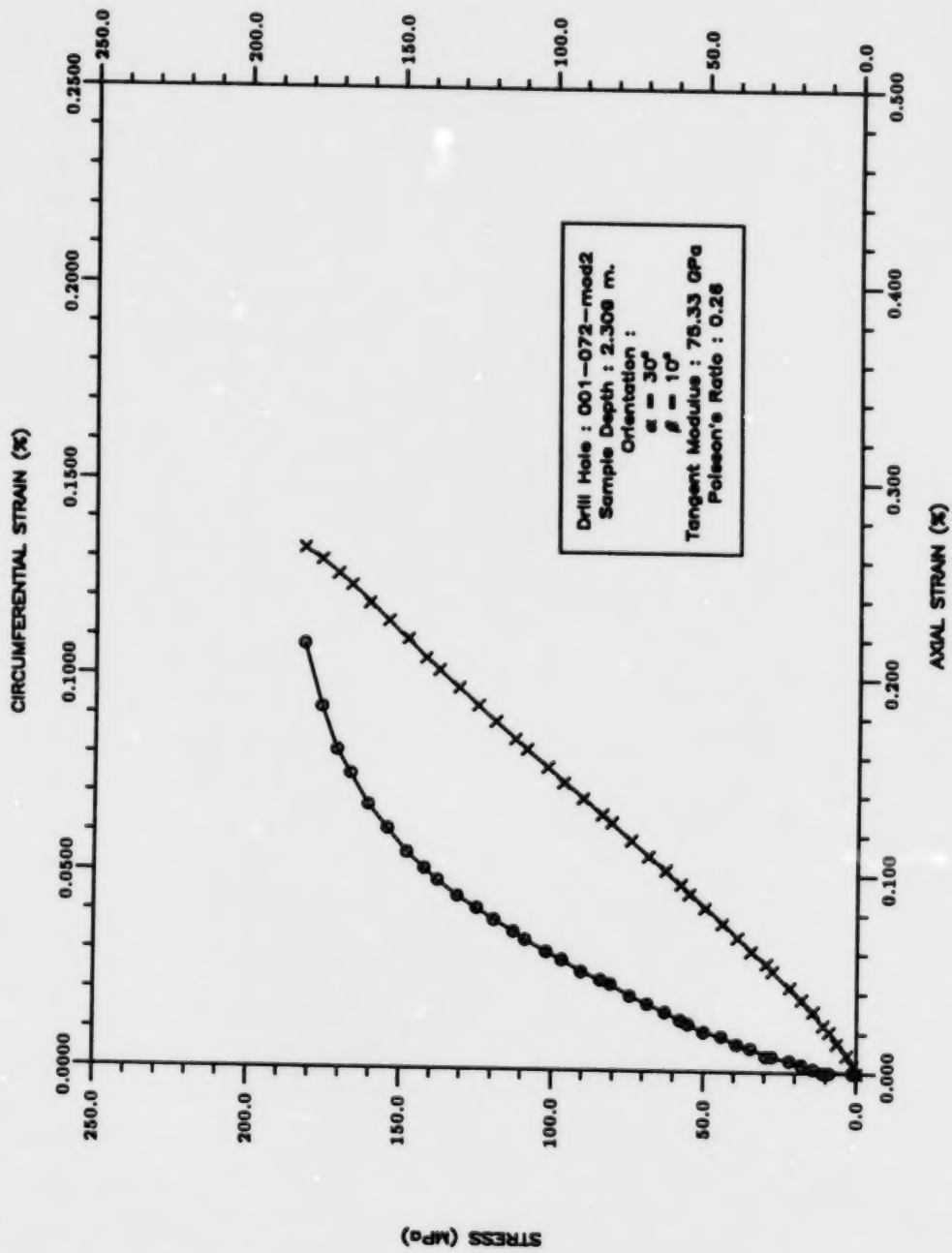


Fig. 18: Axial and circumferential stress/strain curves for anisotropy test specimens.

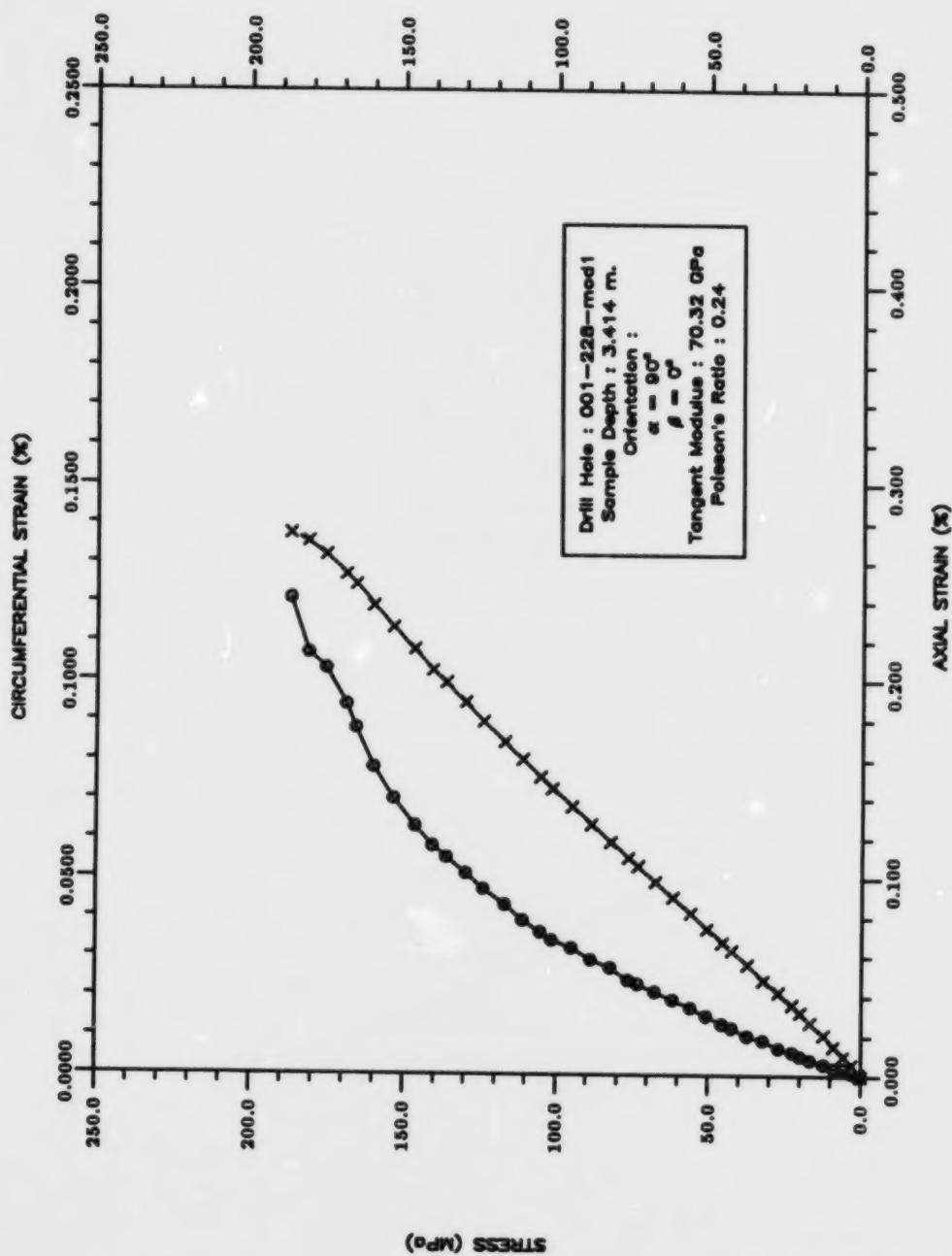


Fig. 19: Axial and circumferential stress/strain curves for anisotropy test specimens.

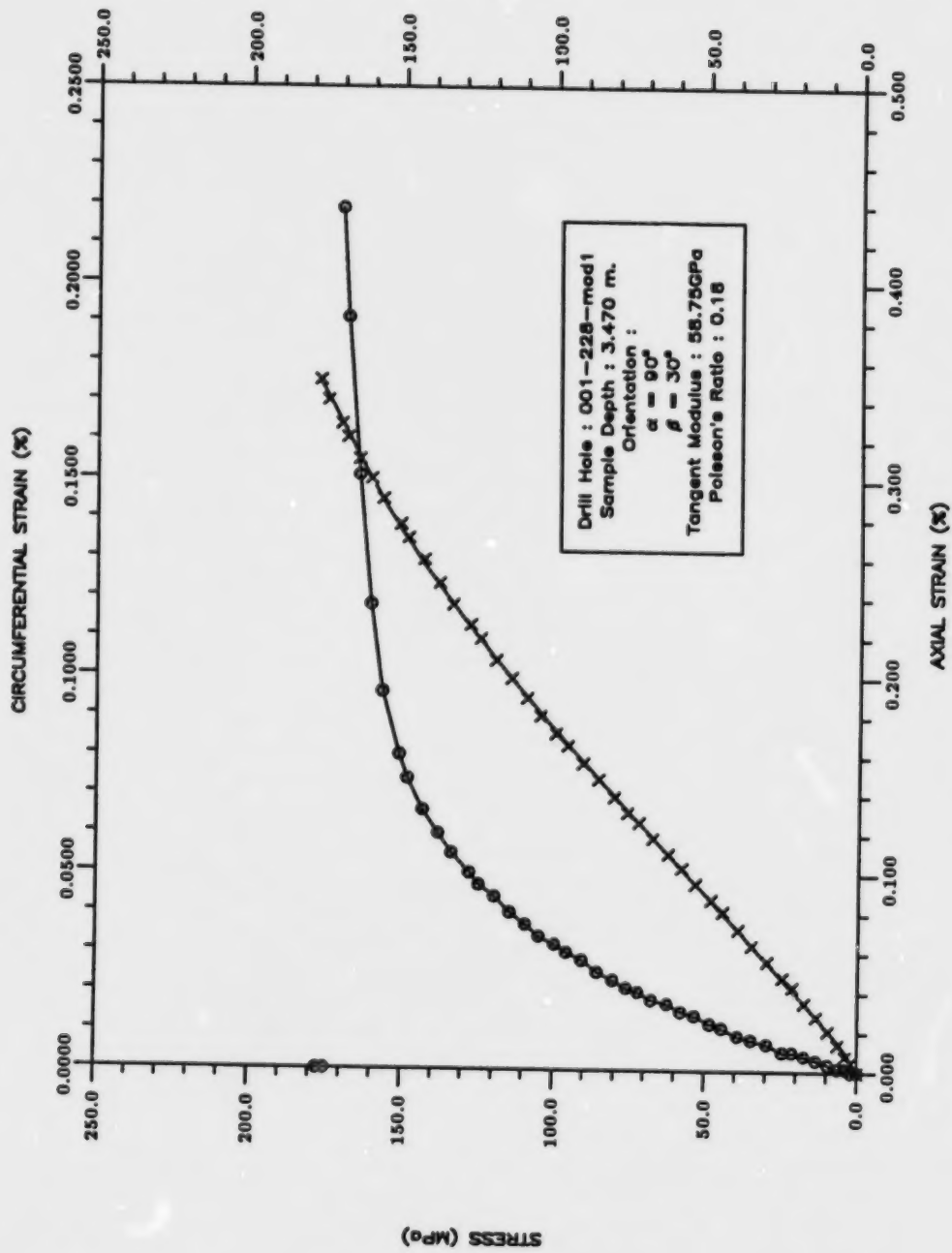


Fig.20: Axial and circumferential stress/strain curves for anisotropy test specimens.

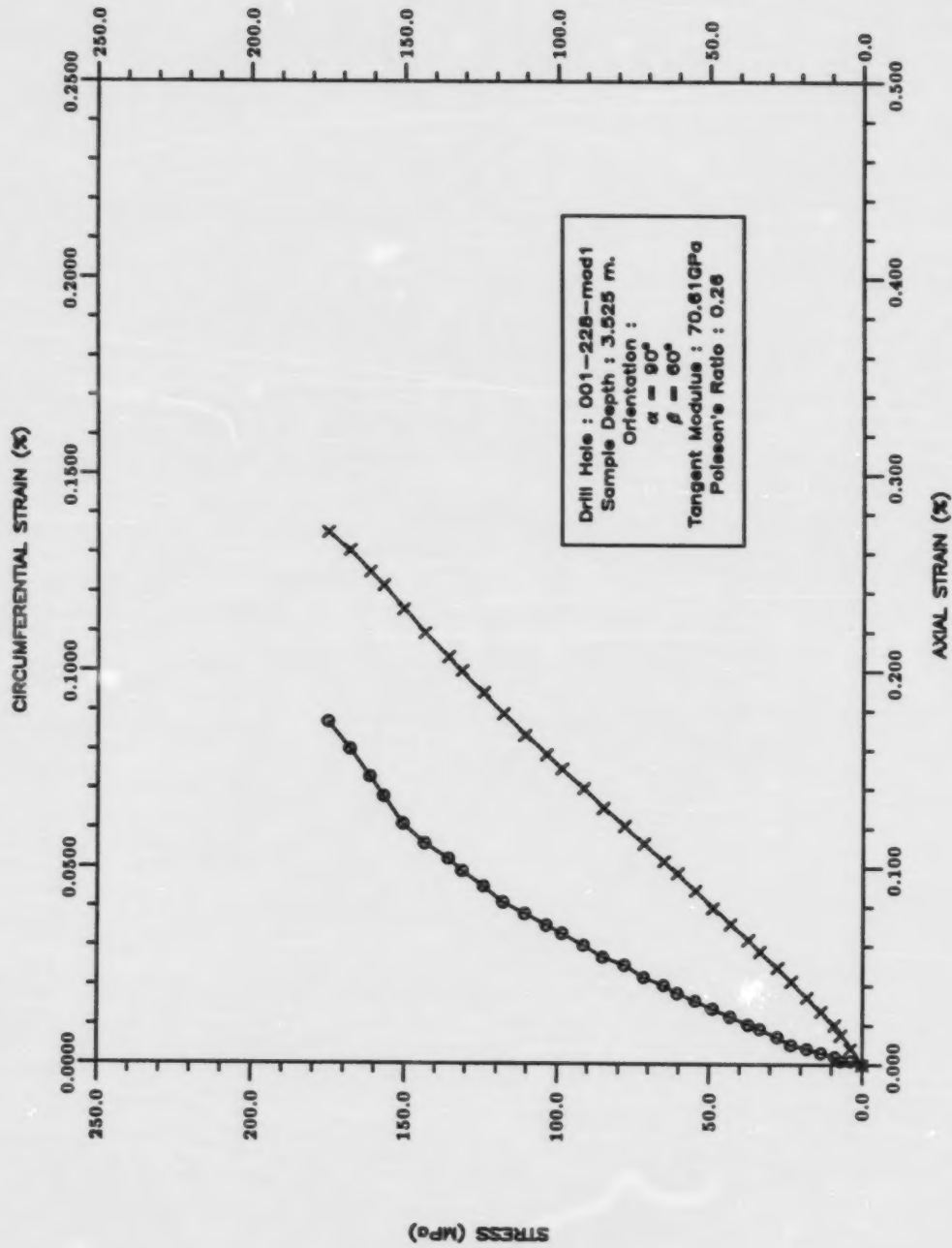


Fig. 2l: Axial and circumferential stress/strain curves for anisotropy test specimens.

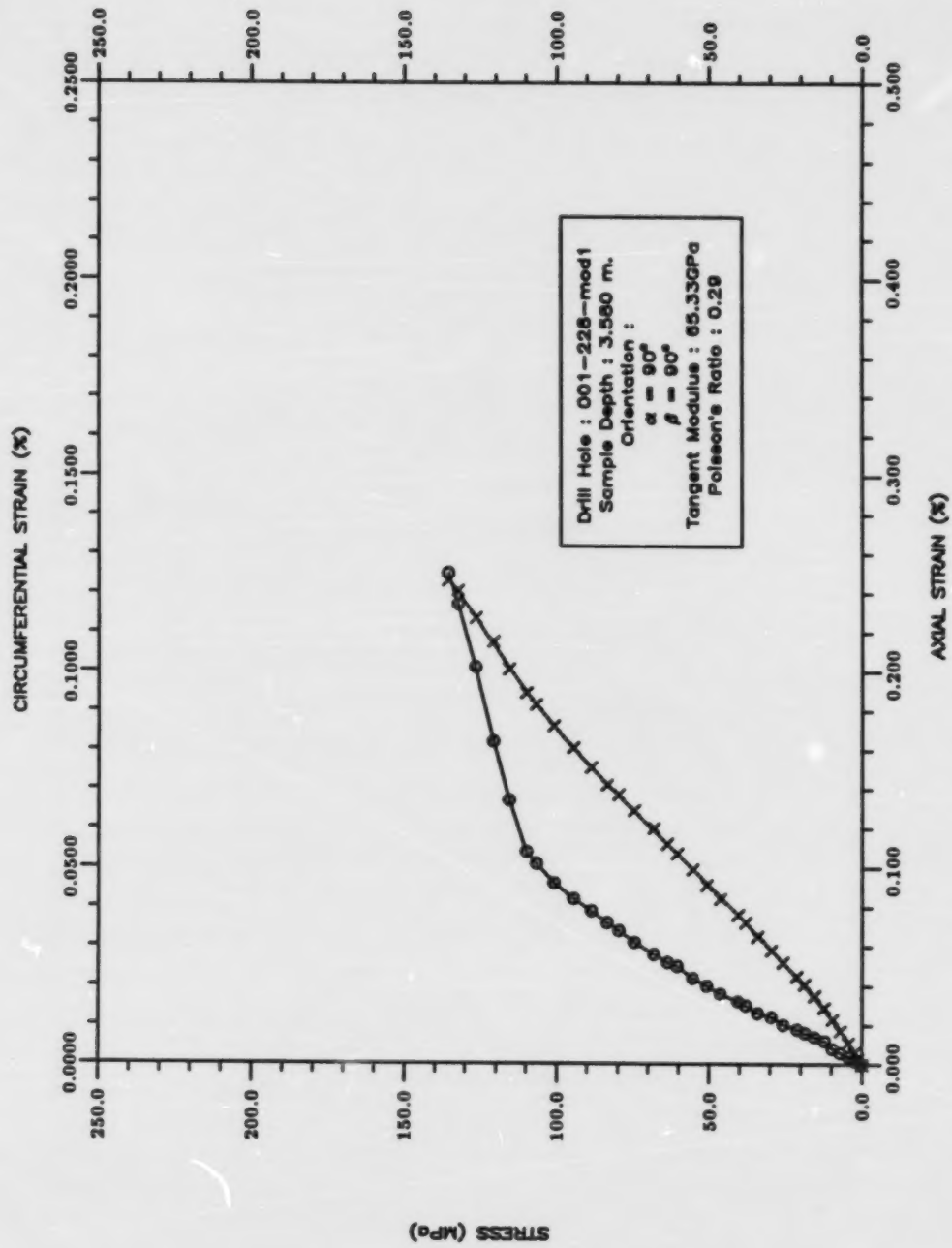


Fig.22: Axial and circumferential stress/strain curves for anisotropy test specimens.

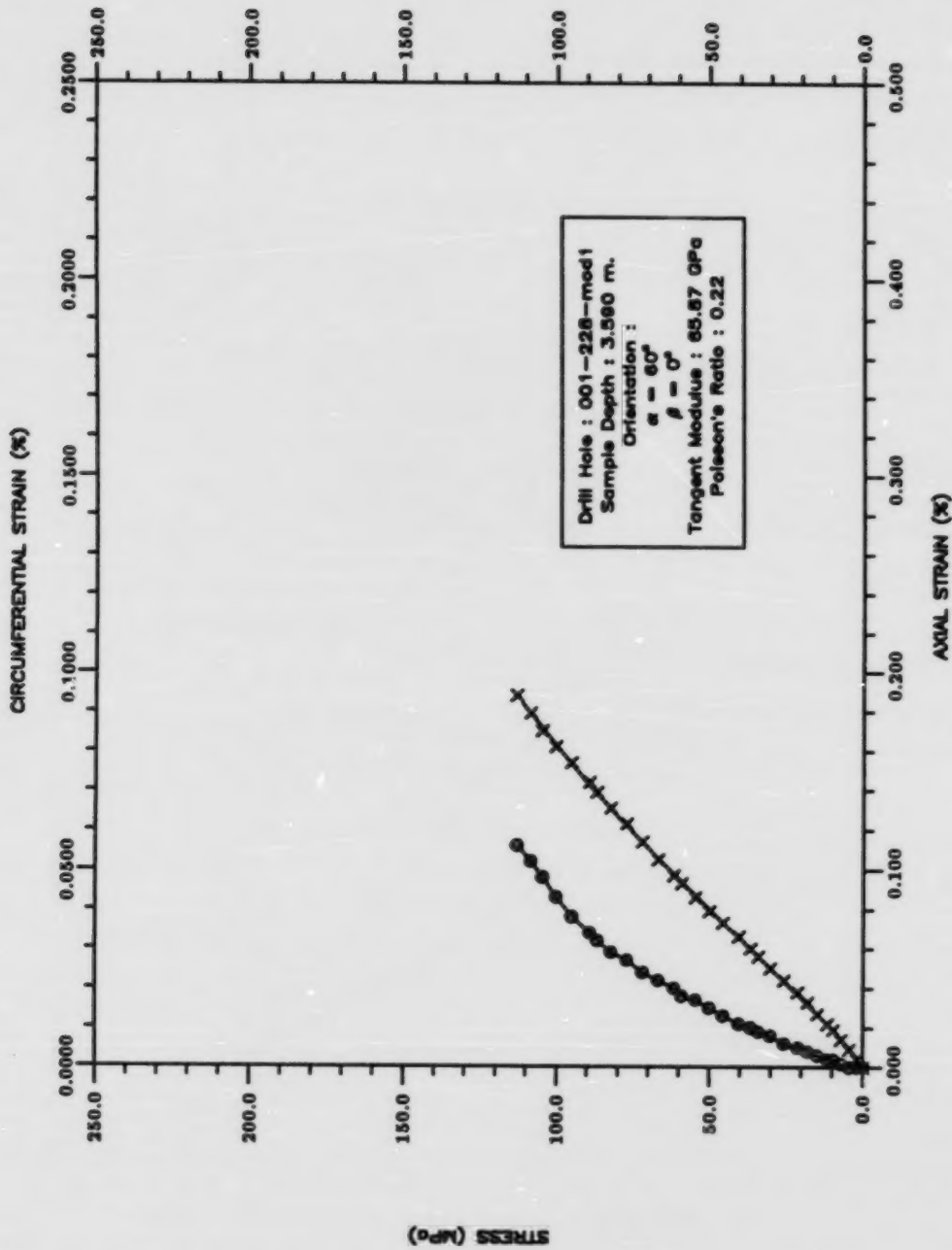


Fig. 23: Axial and circumferential stress/strain curves for anisotropy test specimens.

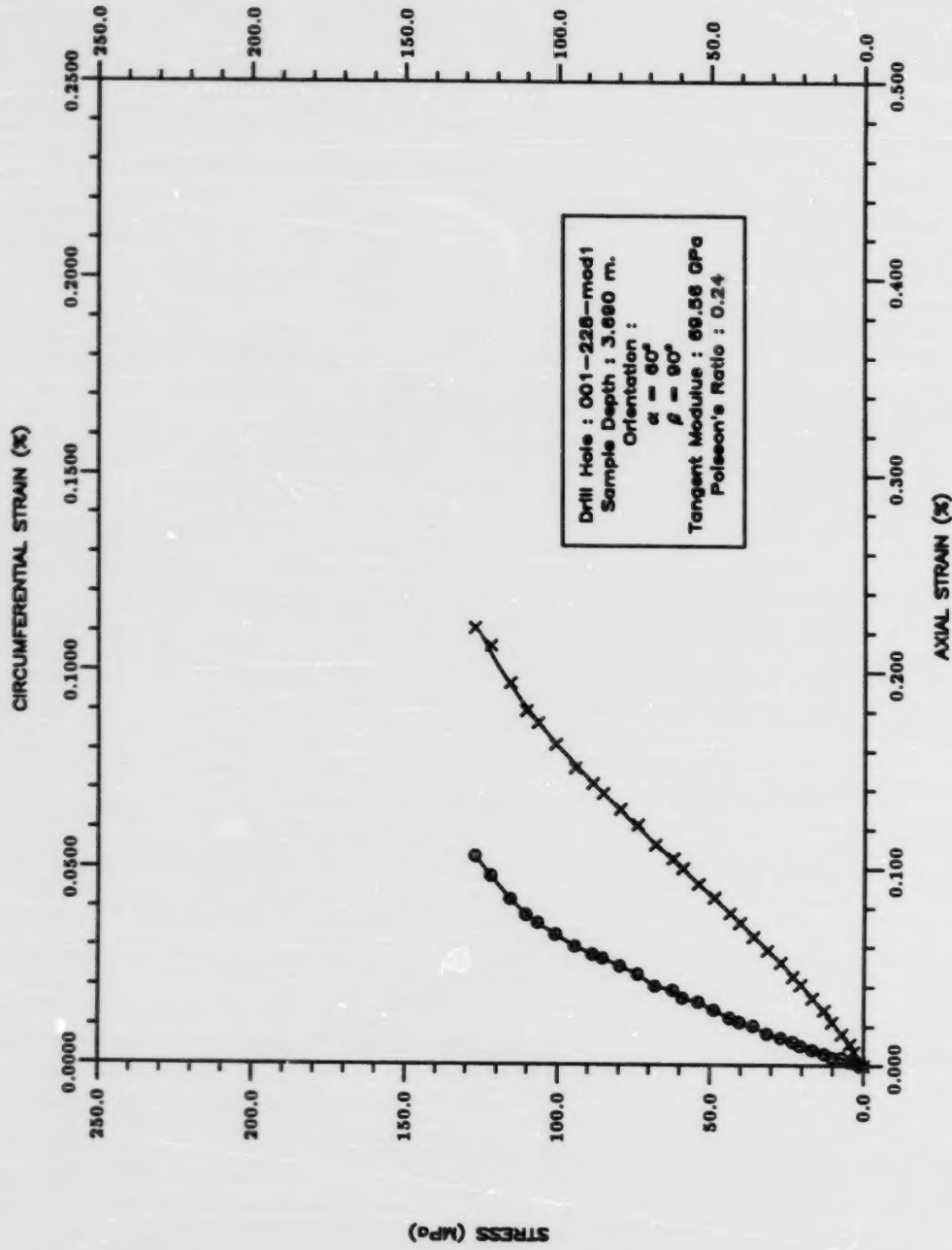


Fig. 24: Axial and circumferential stress/strain curves for anisotropy test specimens.

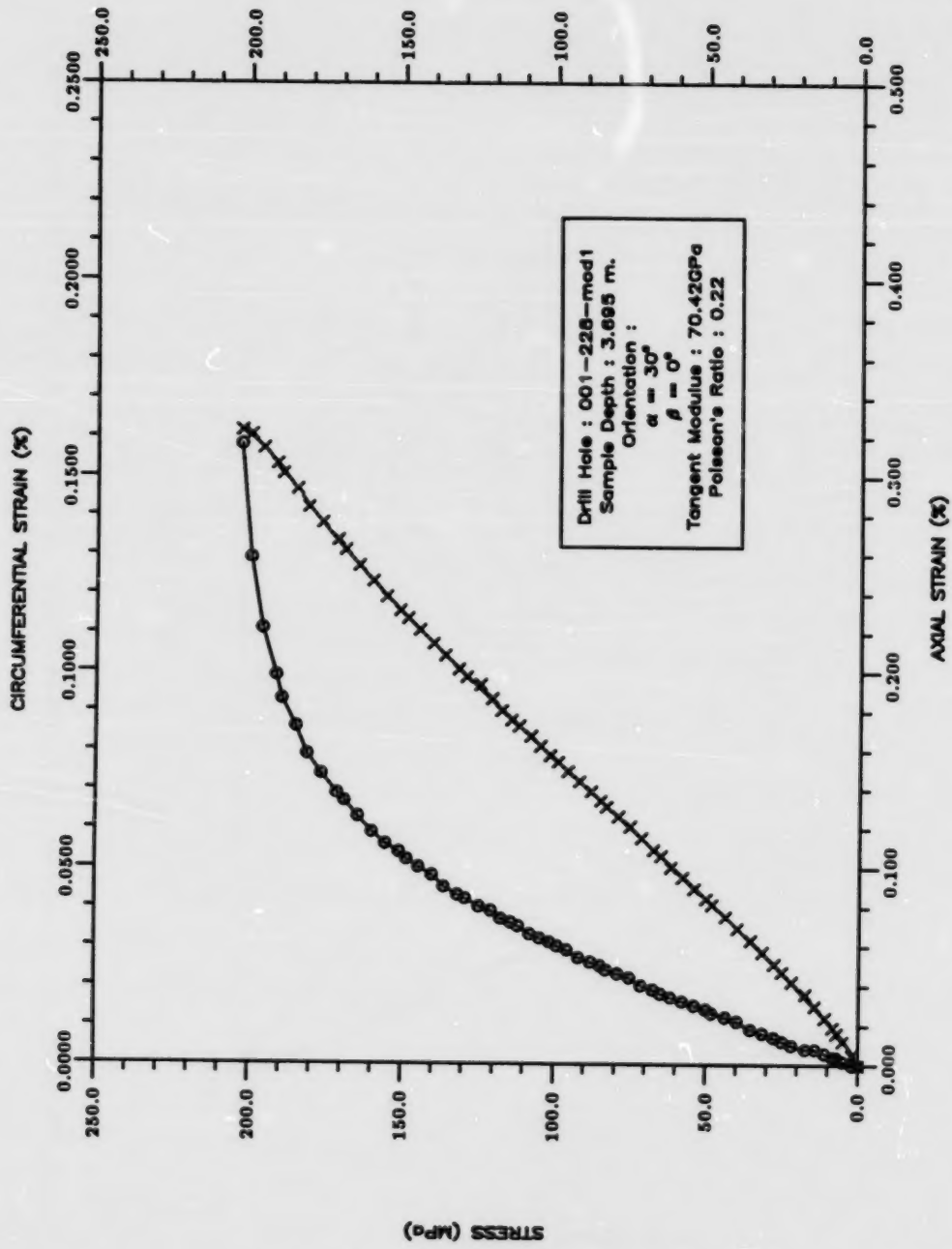


Fig. 25: Axial and circumferential stress/strain curves for anisotropy test specimens.

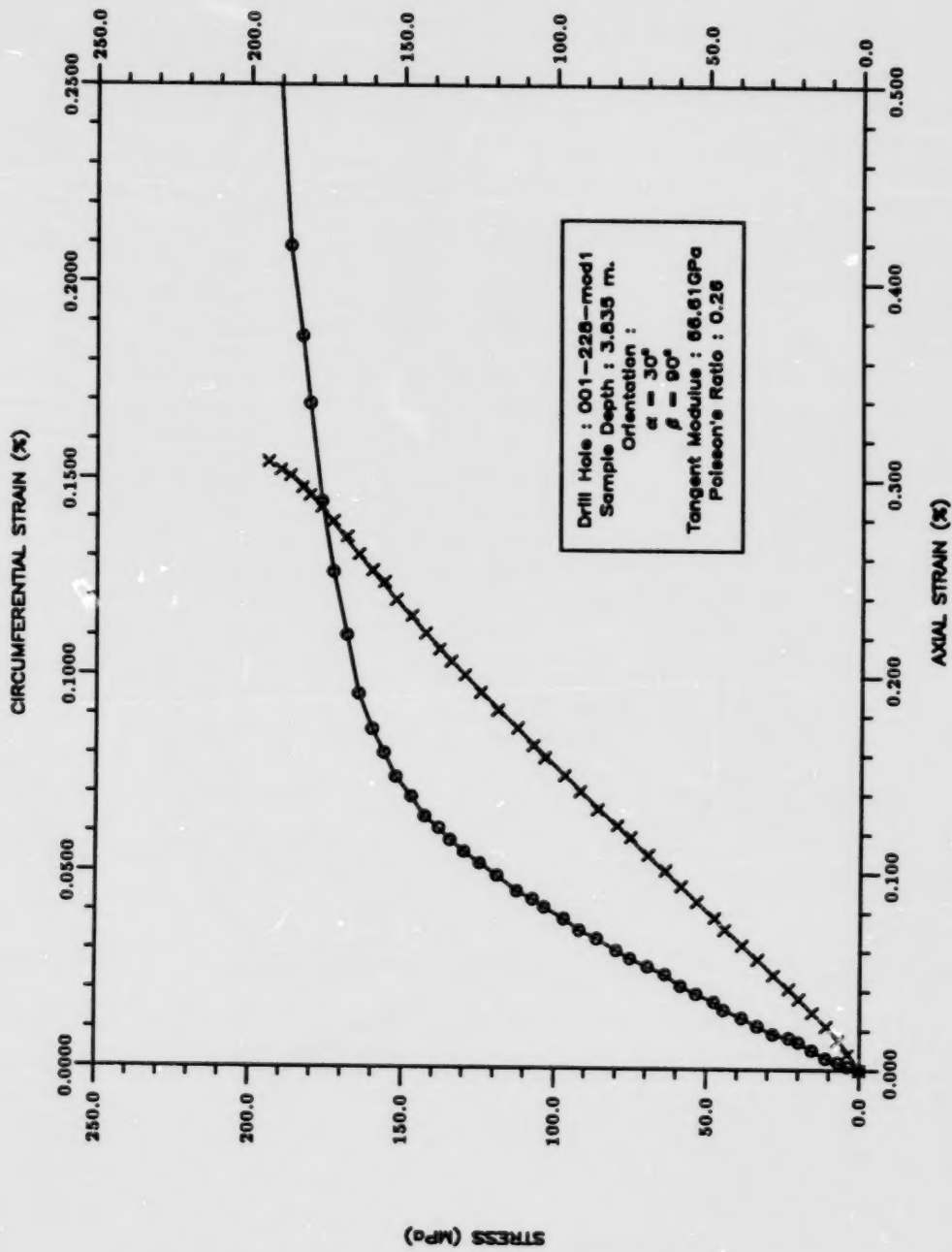


Fig. 26: Axial and circumferential stress/strain curves for anisotropy test specimens.

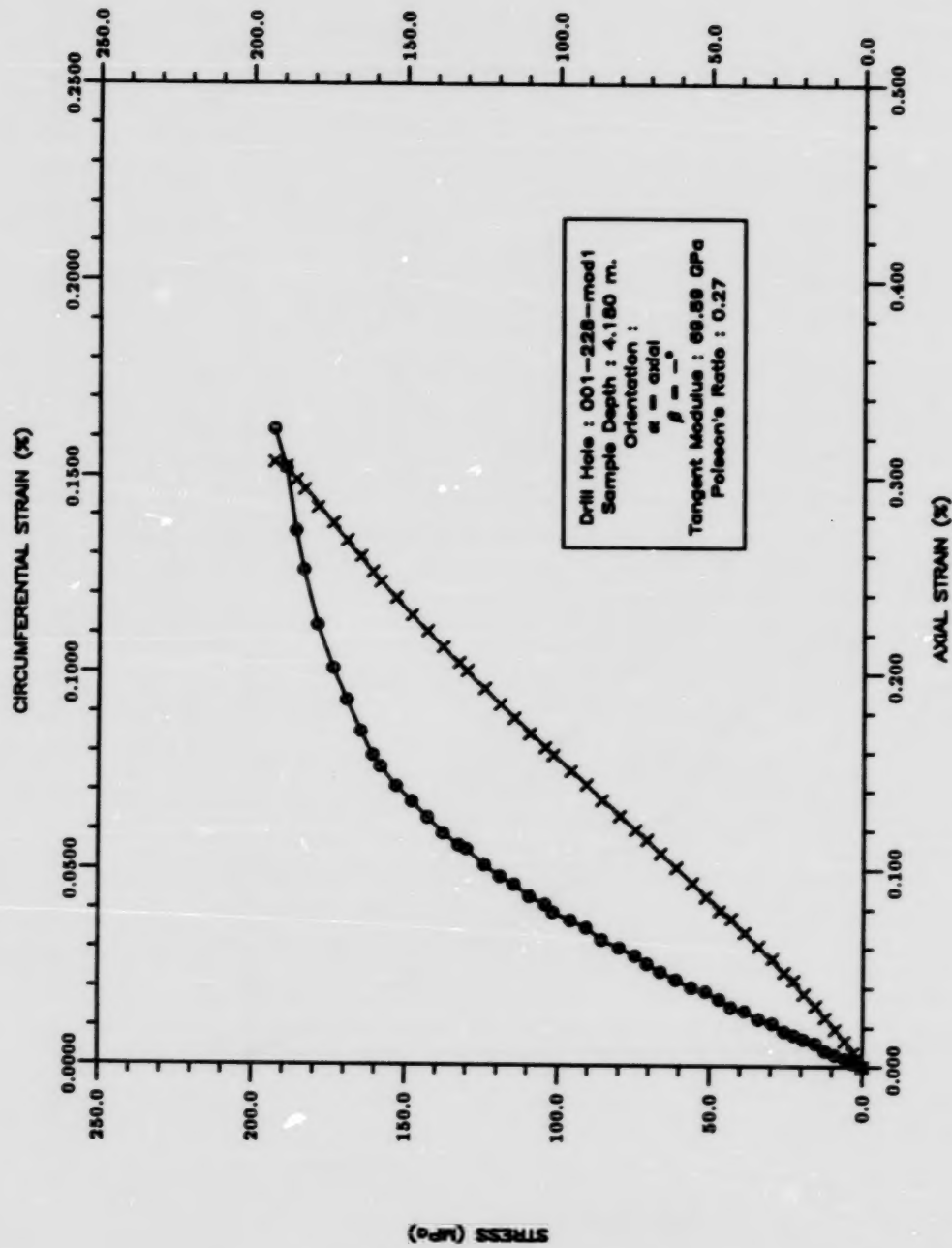


Fig.27: Axial and circumferential stress/strain curves for anisotropy test specimens.

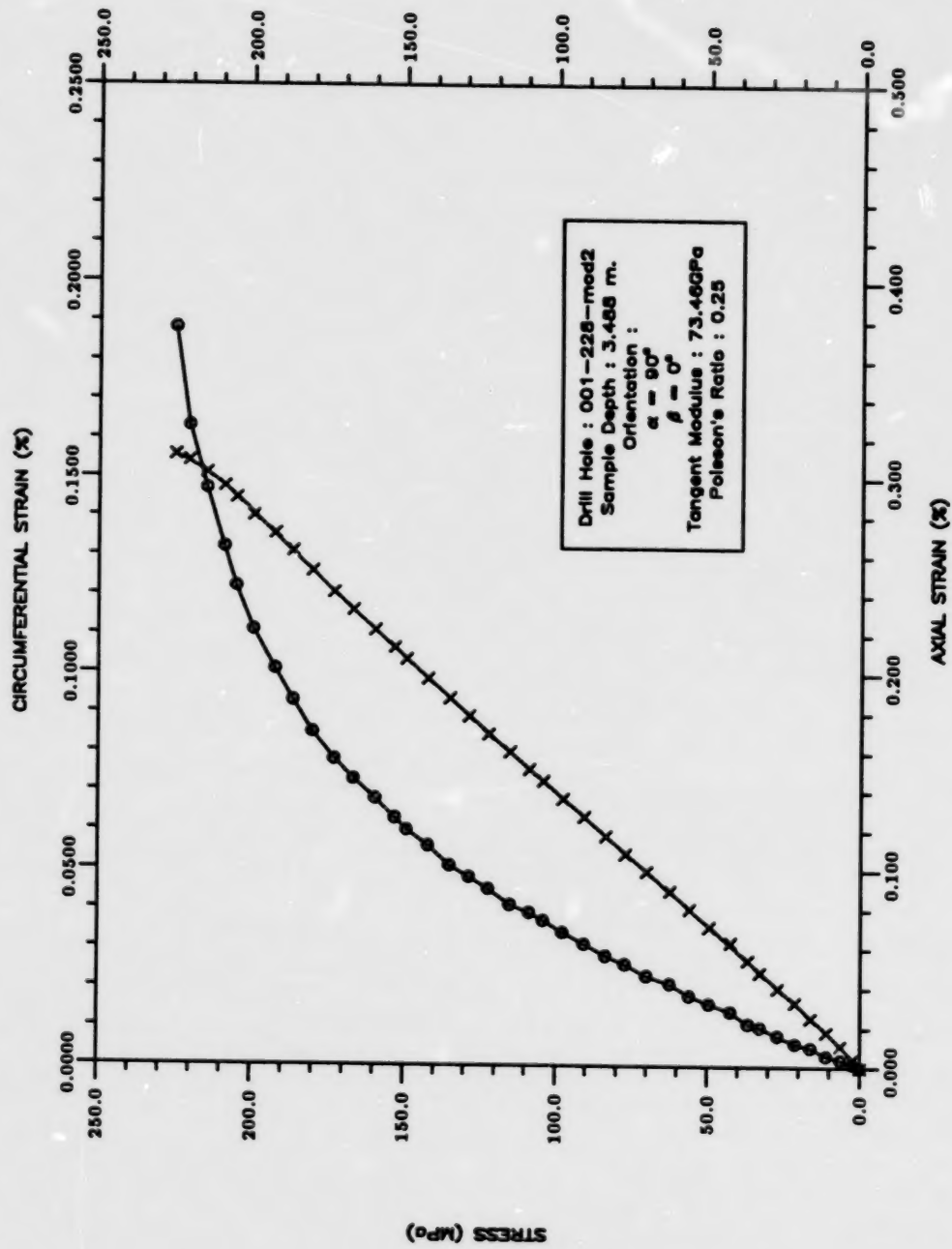


Fig. 28: Axial and circumferential stress/strain curves for anisotropy test specimens.

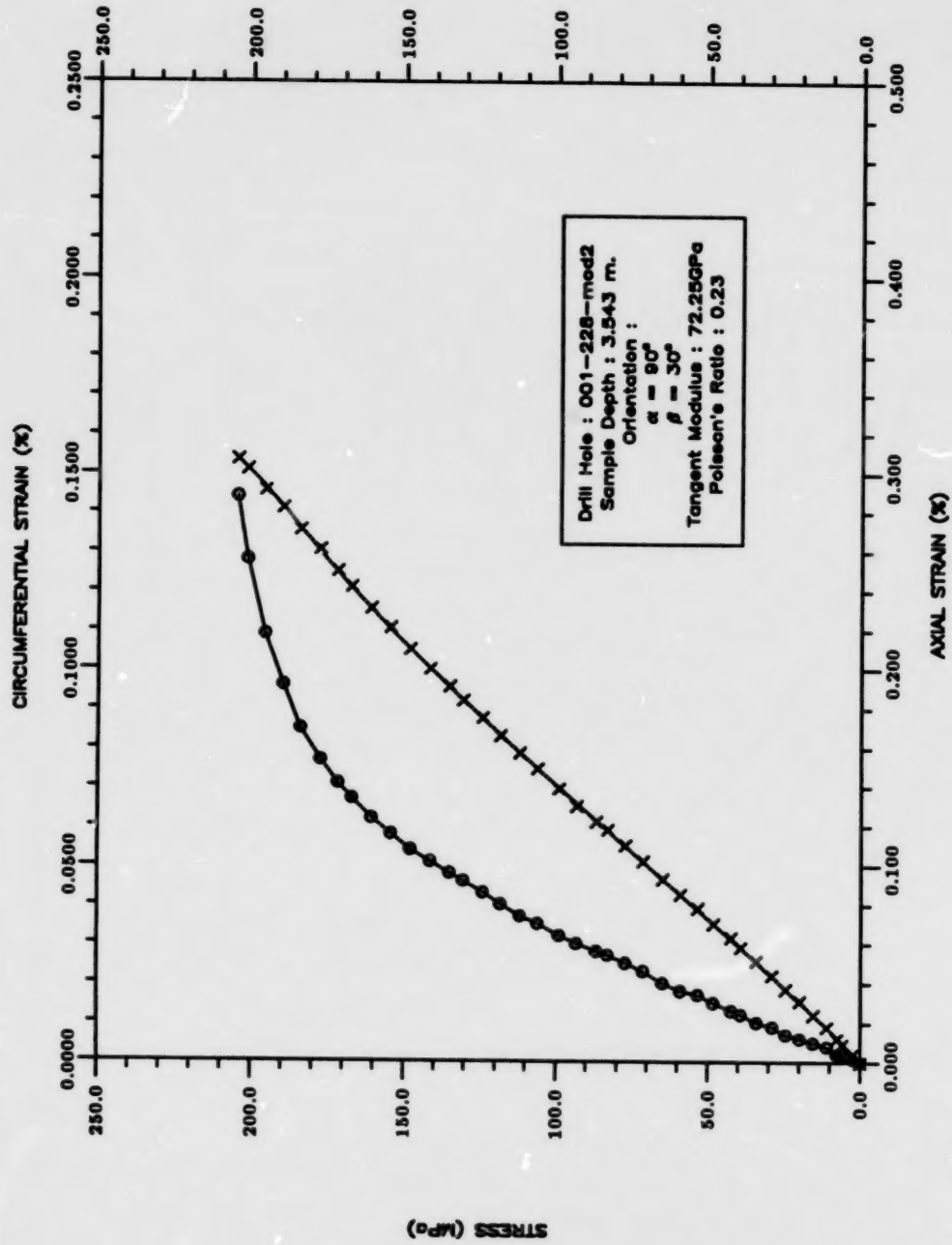


Fig.29: Axial and circumferential stress/strain curves for anisotropy test specimens.

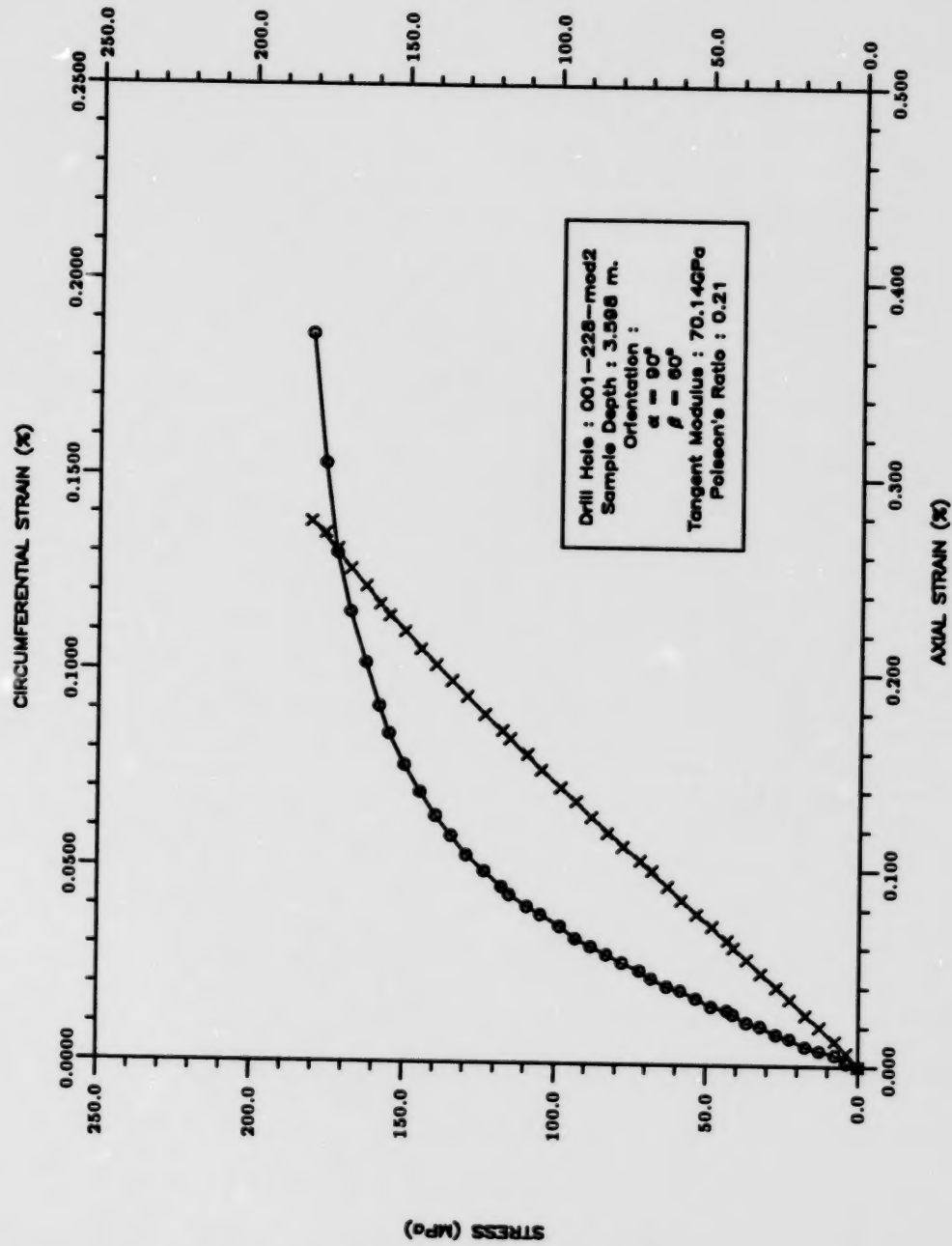


Fig. 30: Axial and circumferential stress/strain curves for anisotropy test specimens.

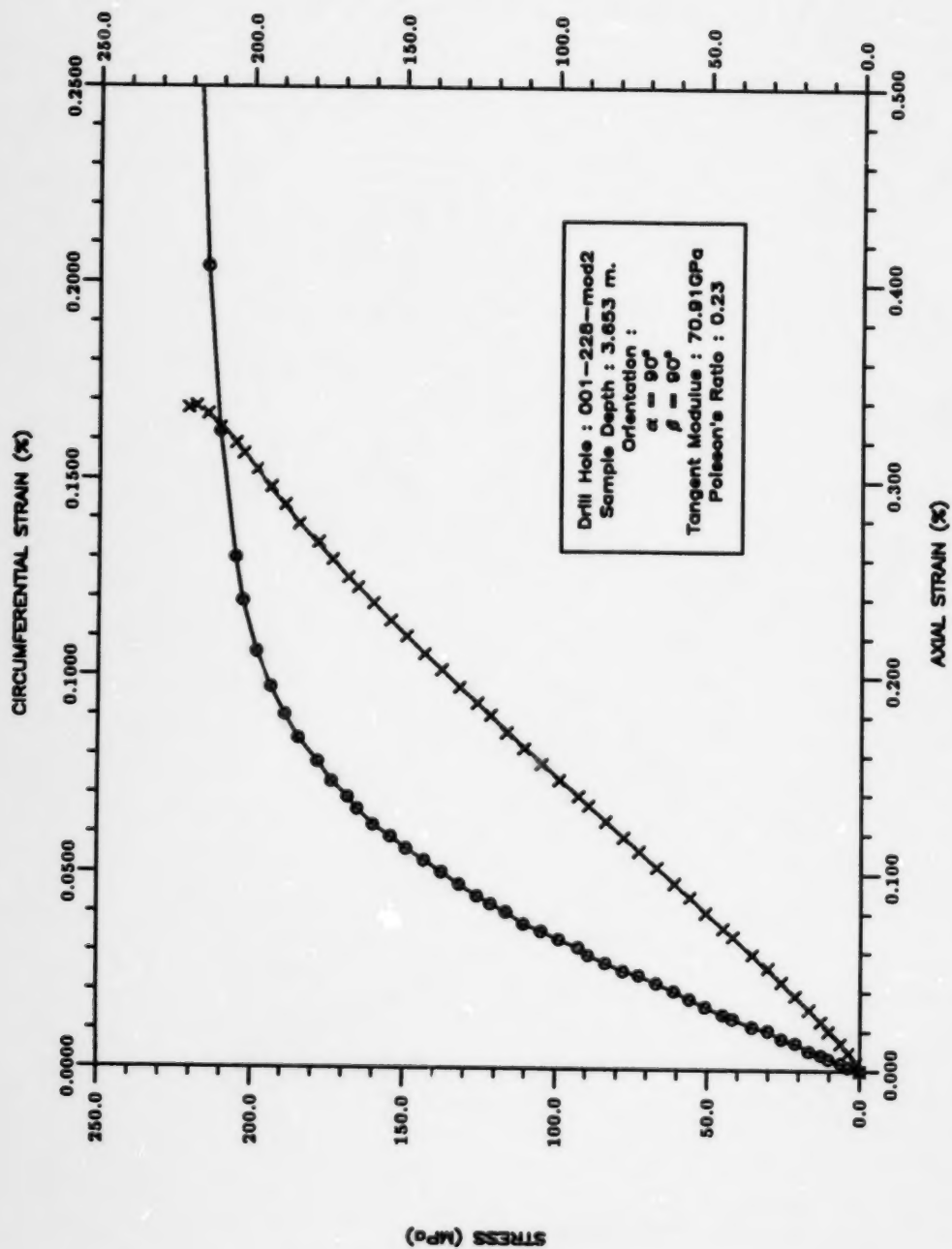


Fig. 31: Axial and circumferential stress/strain curves for anisotropy test specimens.

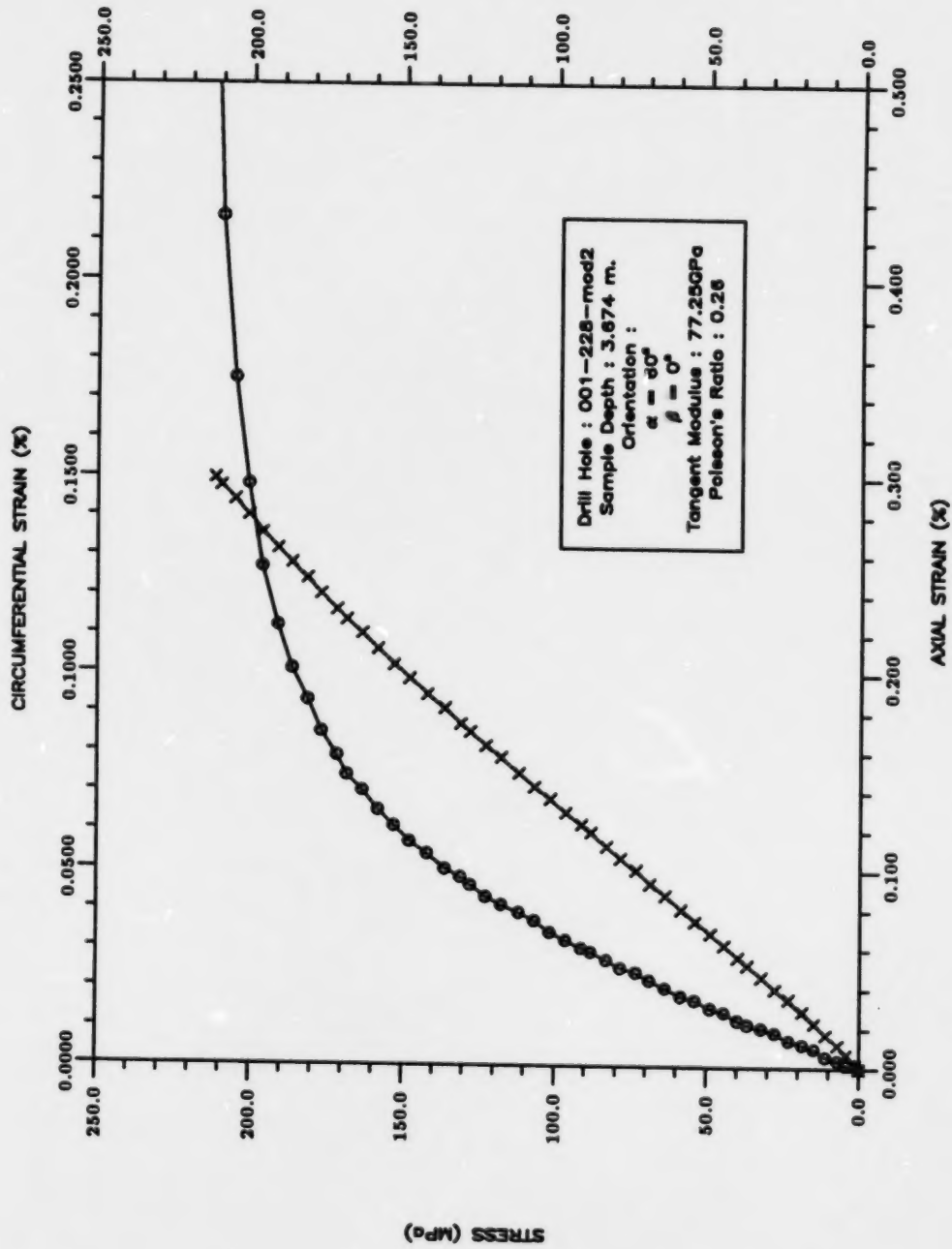


Fig. 32: Axial and circumferential stress/strain curves for anisotropy test specimens.

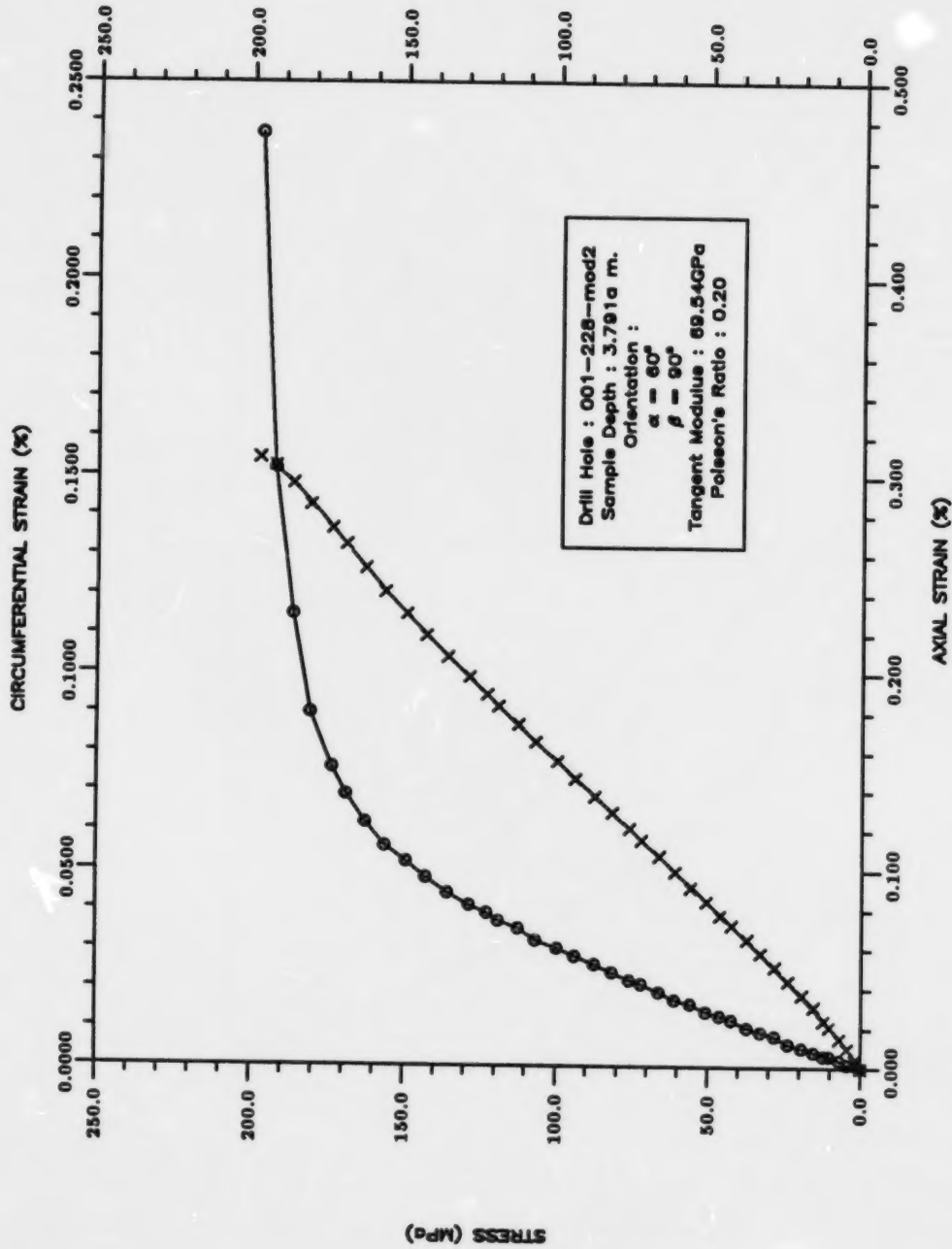


Fig. 33: Axial and circumferential stress/strain curves for anisotropy test specimens.

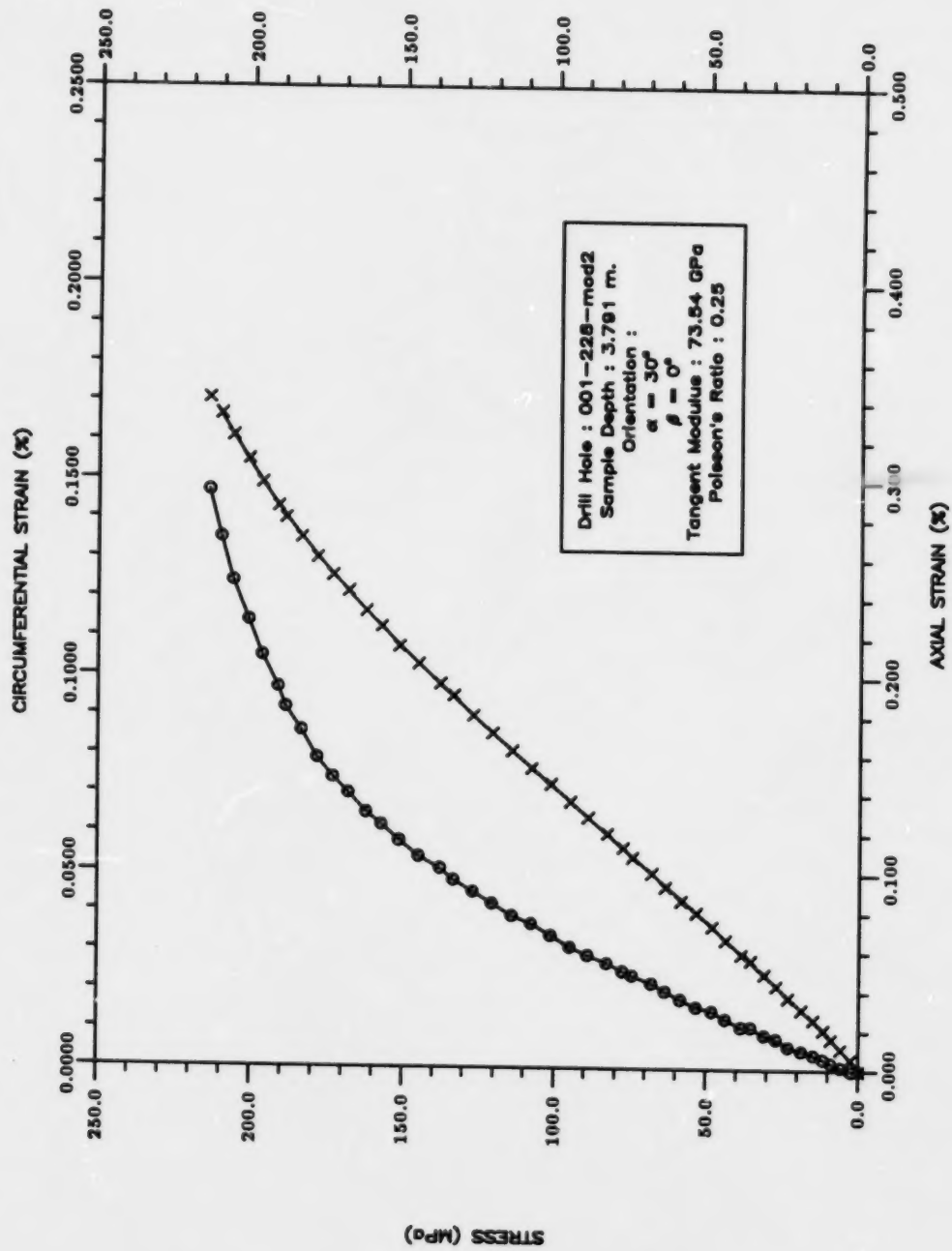


Fig. 34: Axial and circumferential stress/strain curves for anisotropy test specimens.

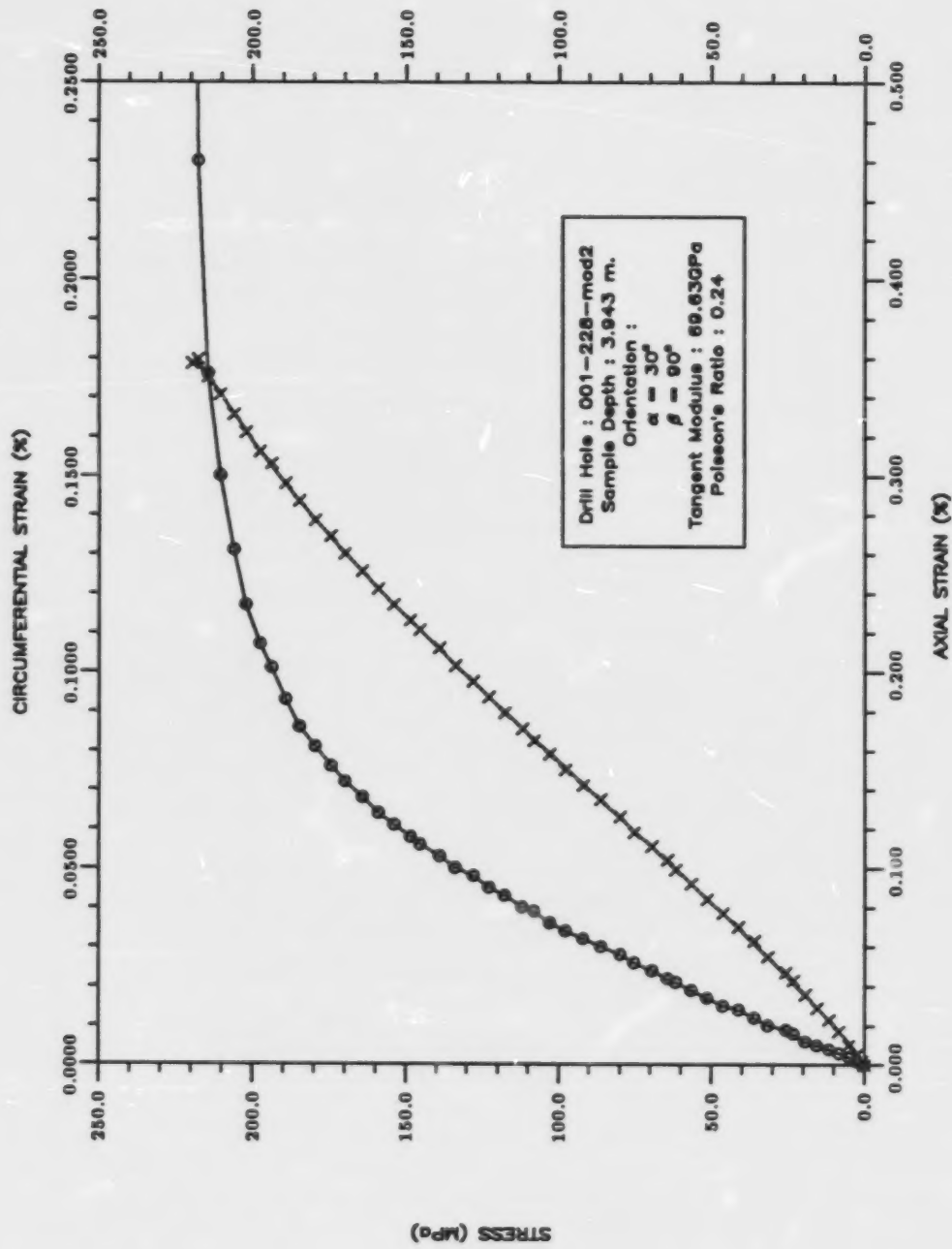


Fig. 35: Axial and circumferential stress/strain curves for anisotropy test specimens.

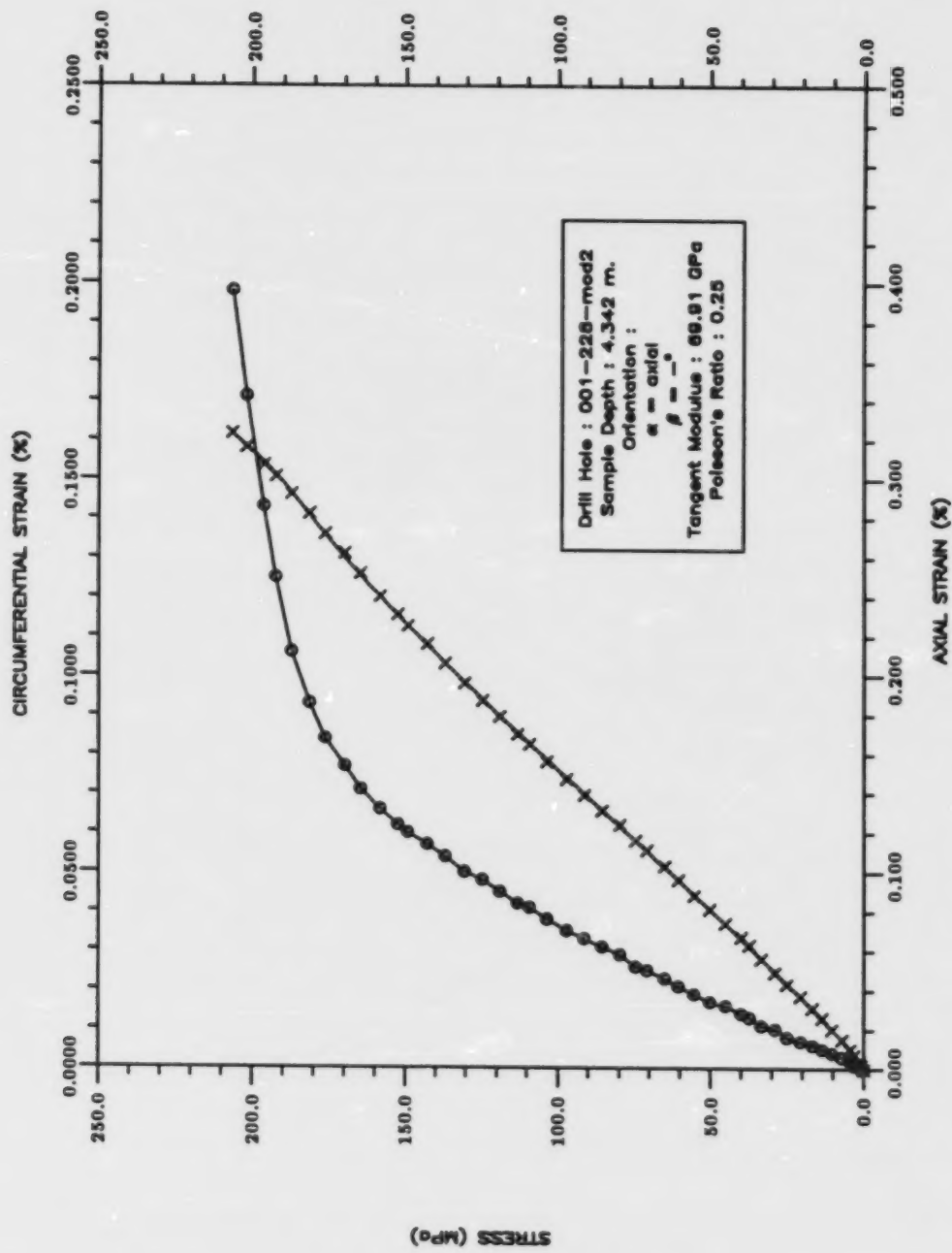


Fig. 36: Axial and circumferential stress/strain curves for anisotropy test specimens.

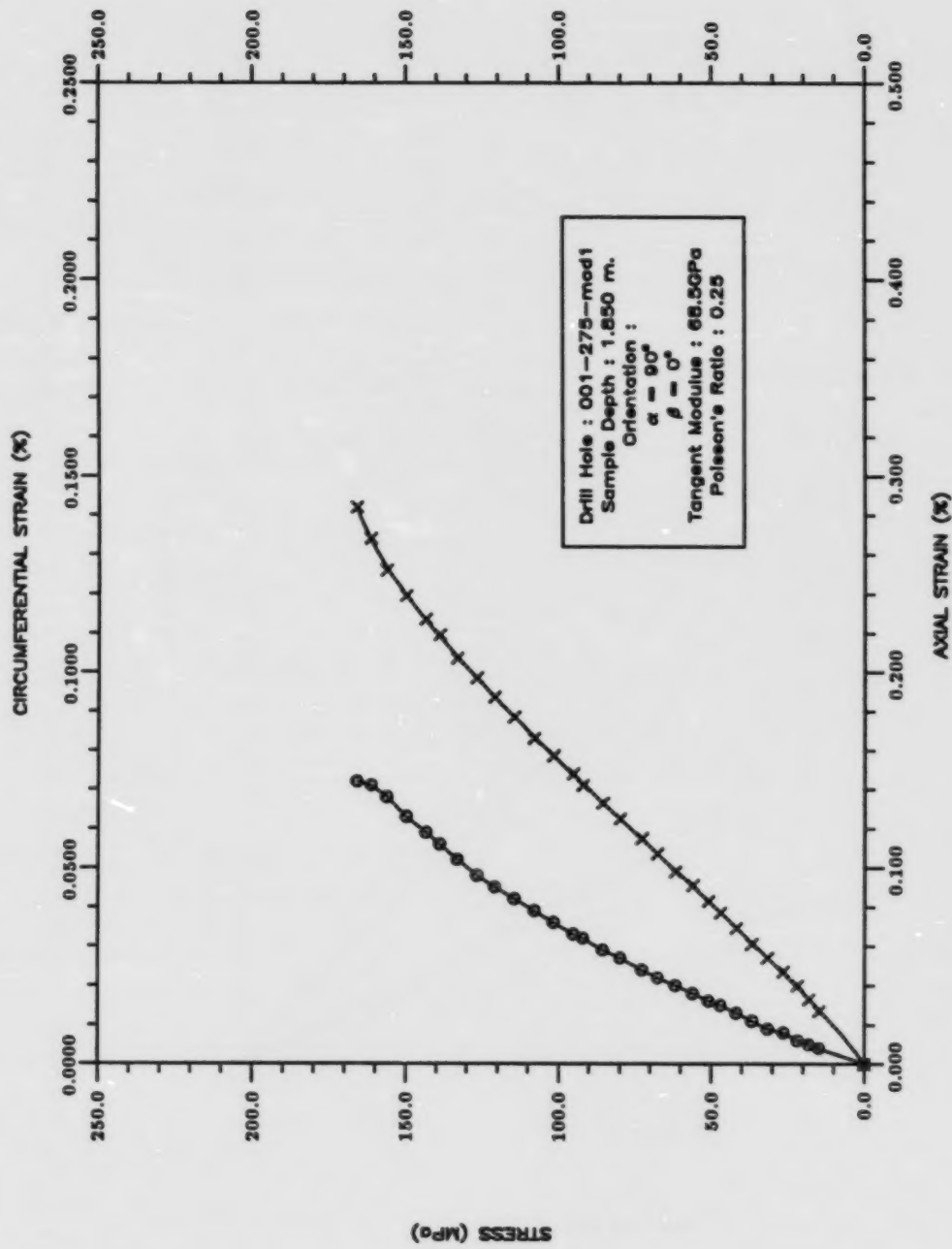


Fig. 37: Axial and circumferential stress/strain curves for anisotropy test specimens.

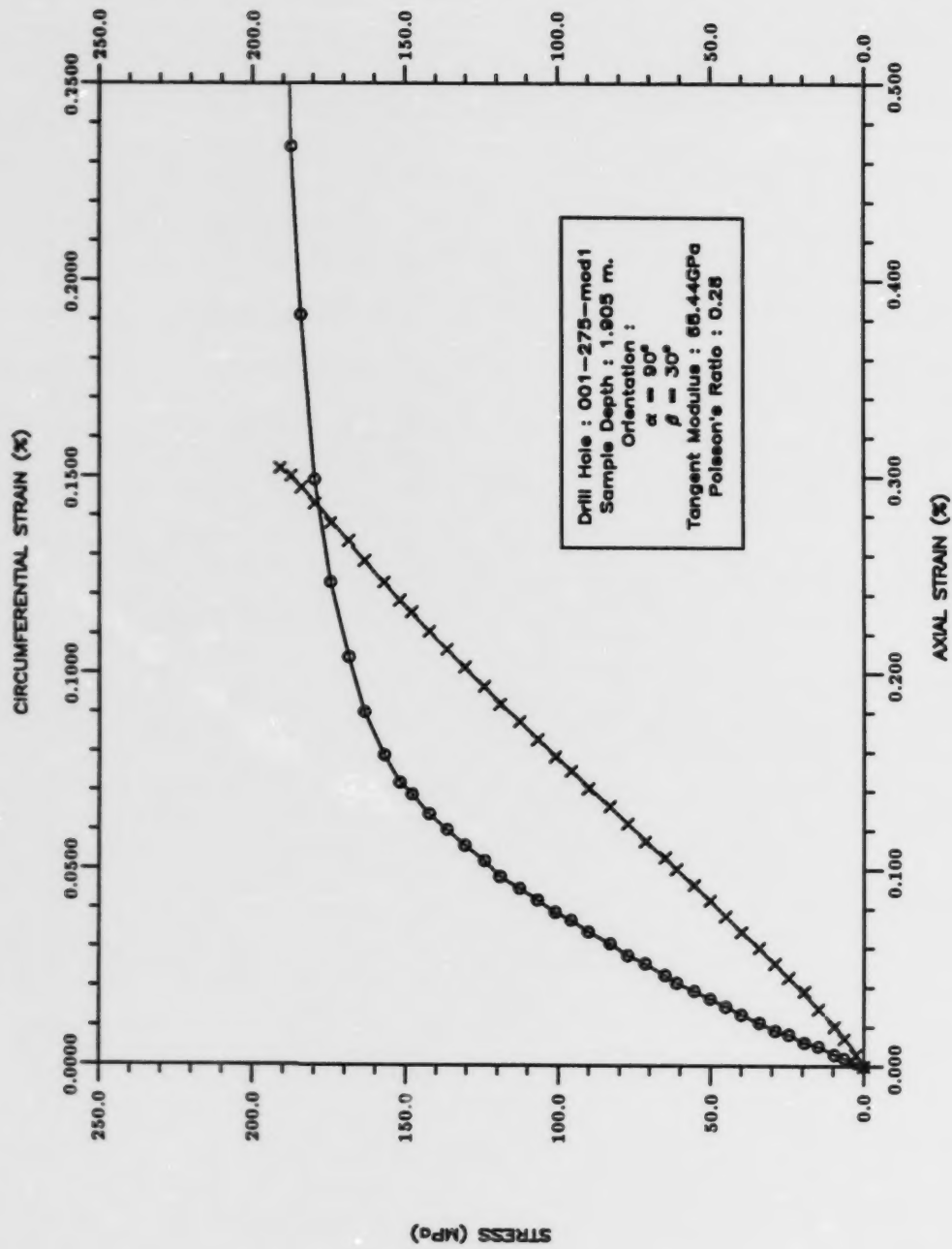


Fig. 38: Axial and circumferential stress/strain curves for anisotropy test specimens.

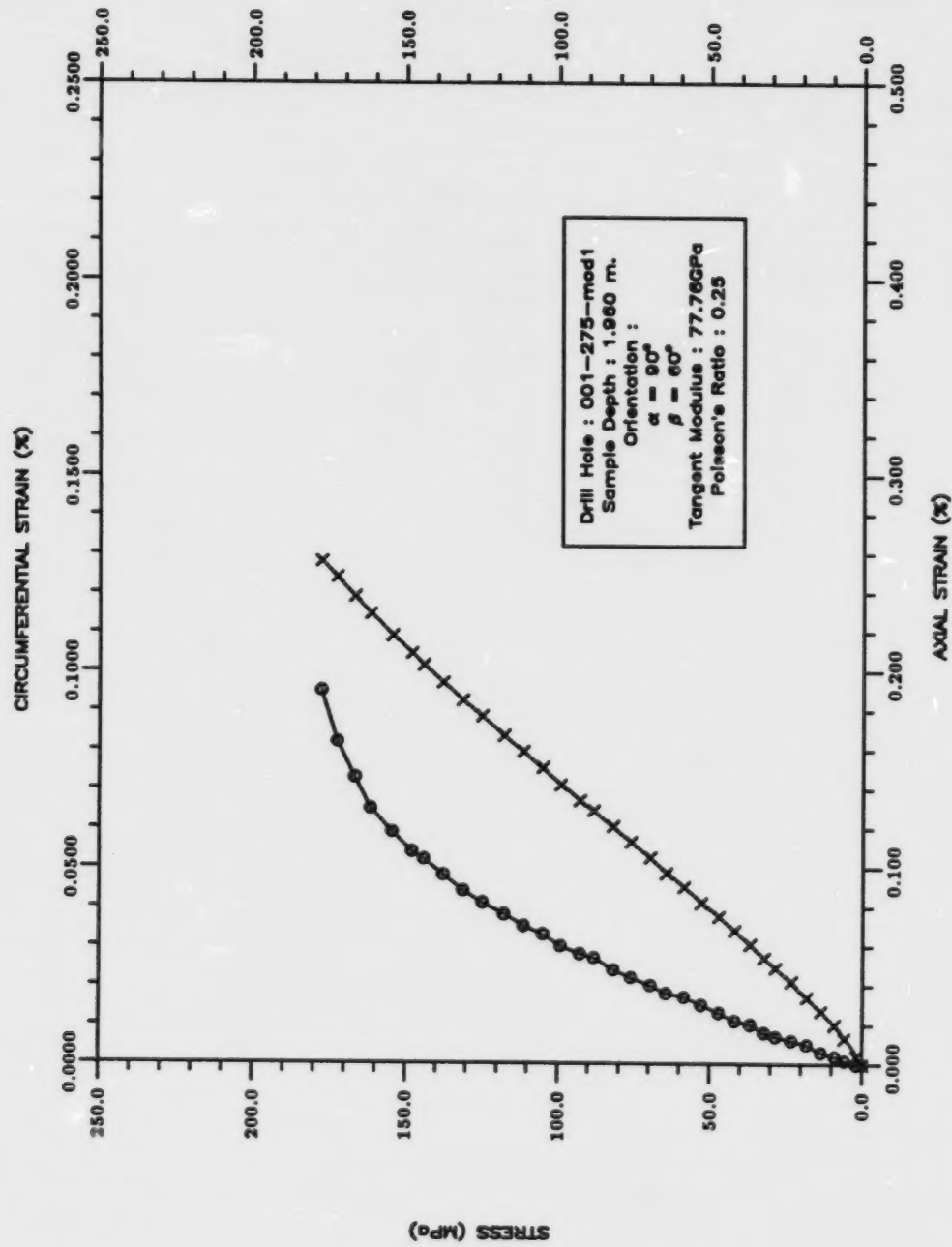


Fig. 39: Axial and circumferential stress/strain curves for anisotropy test specimens.

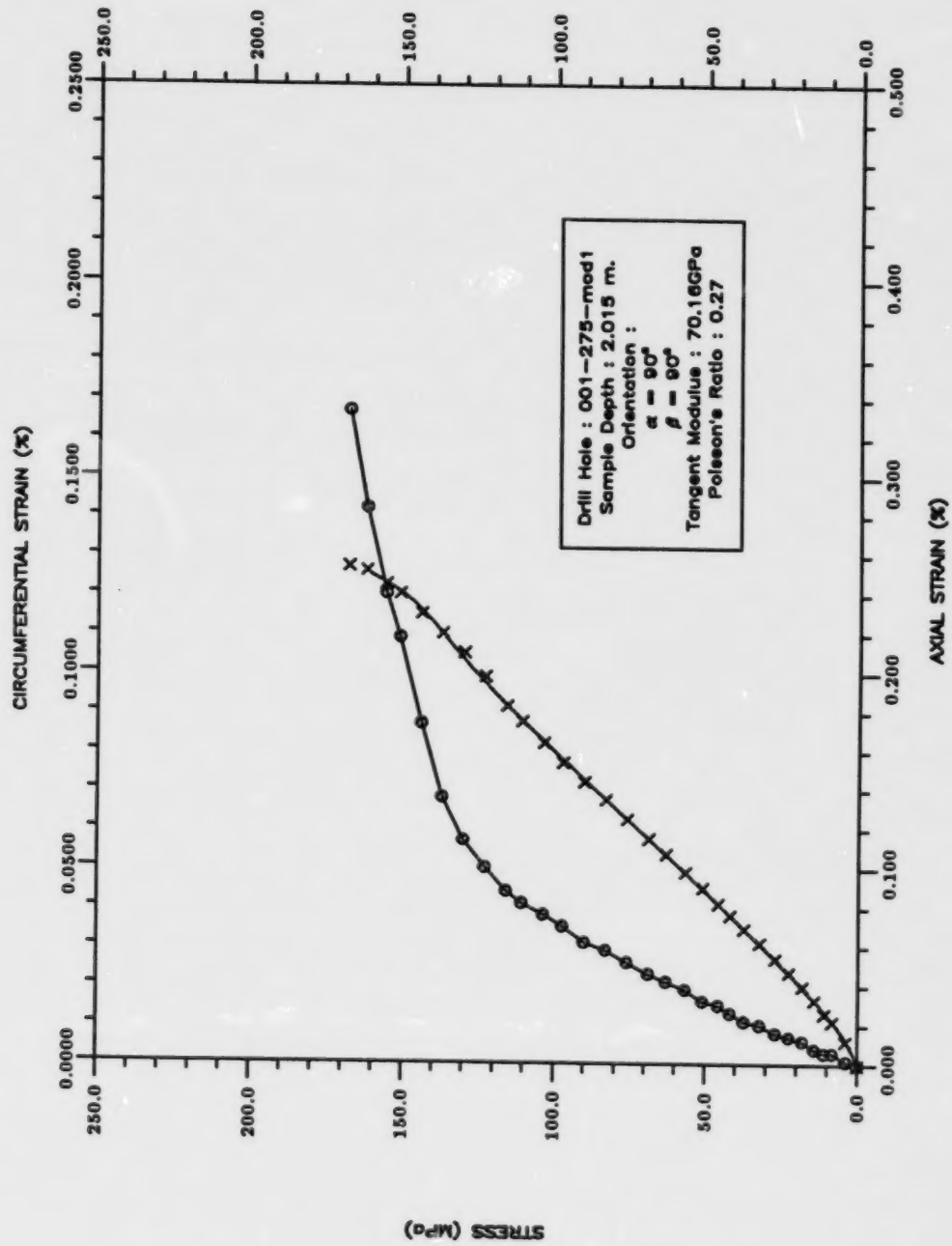


Fig.40: Axial and circumferential stress/strain curves for anisotropy test specimens.

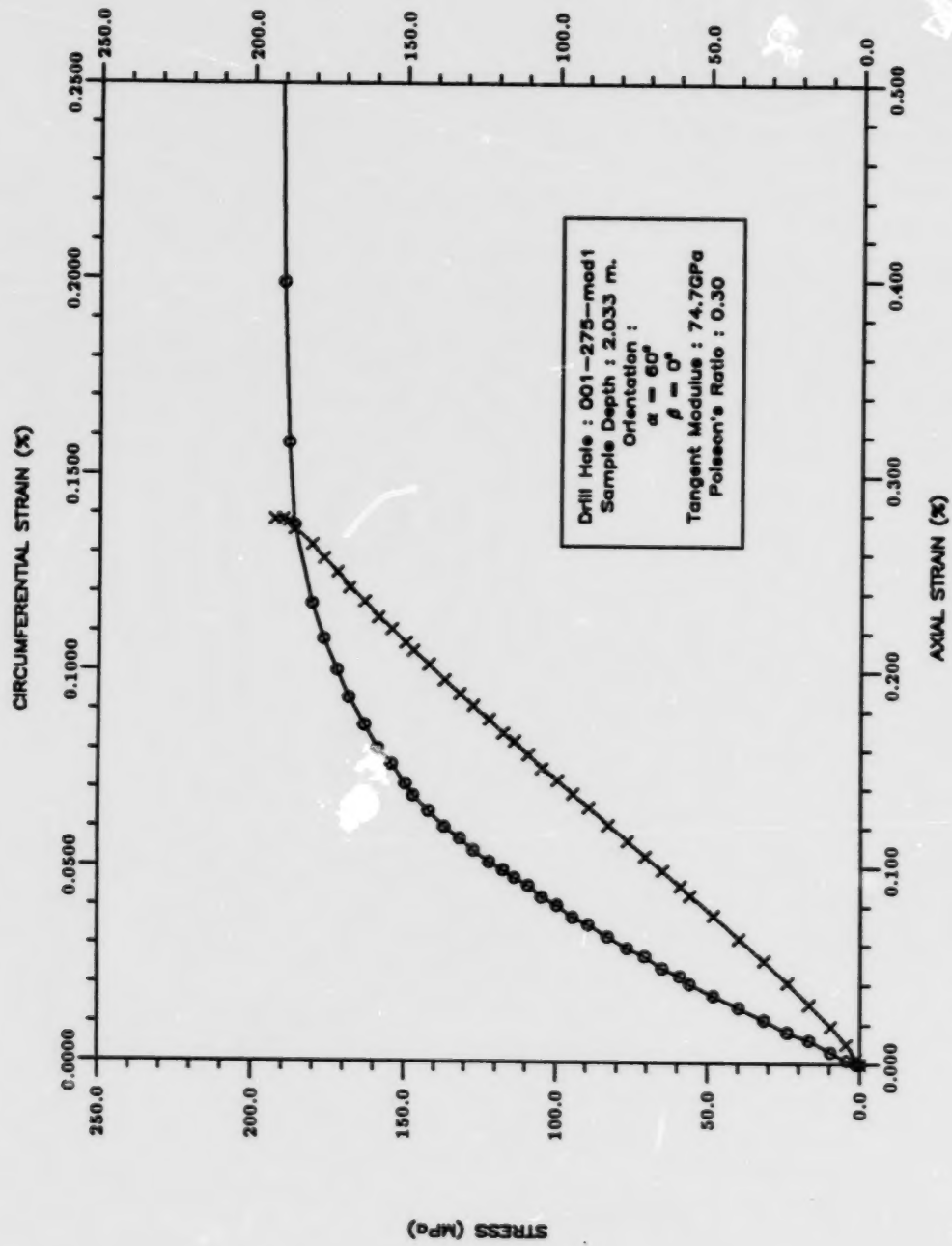


Fig. 41: Axial and circumferential stress/strain curves for anisotropy test specimens.

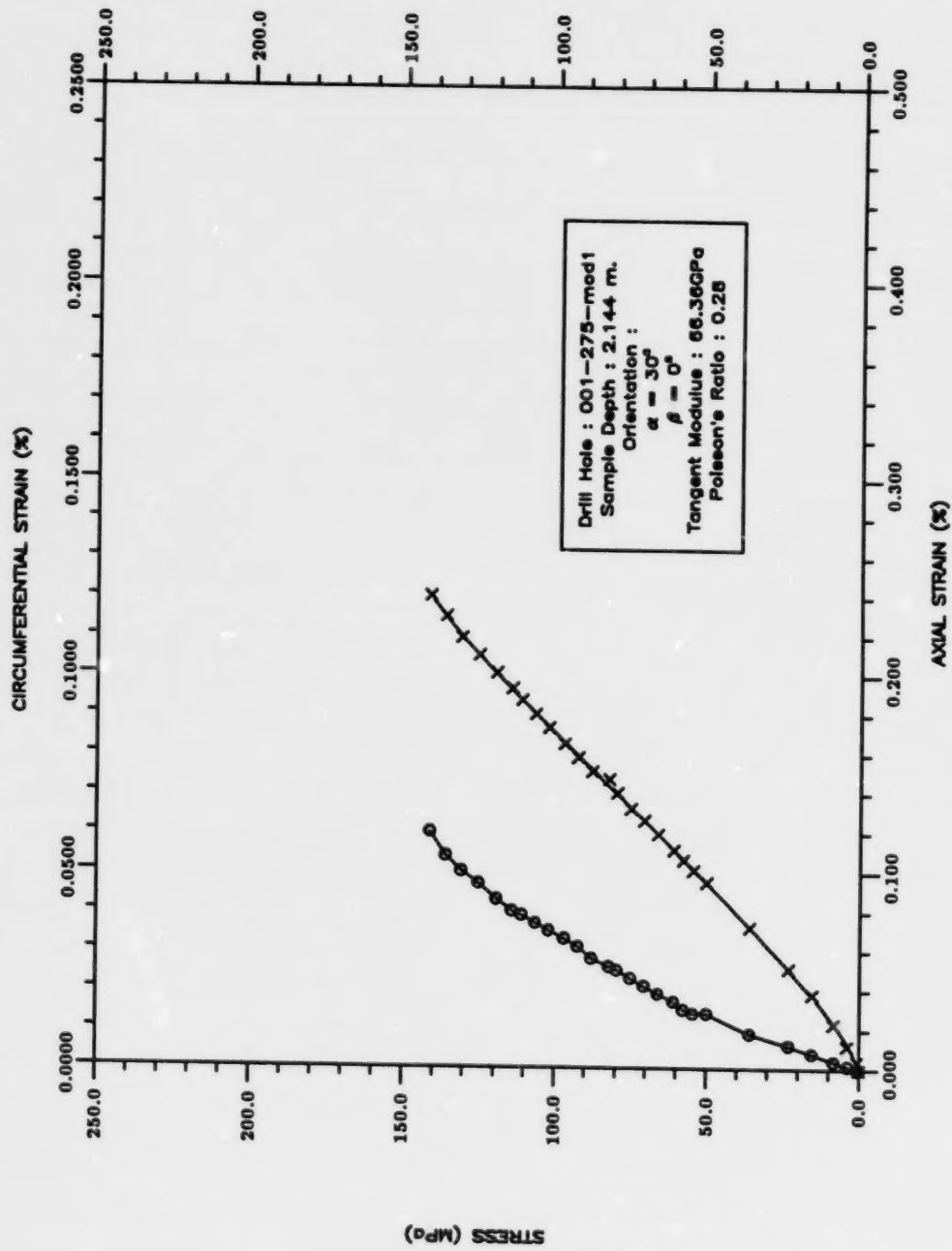


Fig. 42: Axial and circumferential stress/strain curves for anisotropy test specimens.

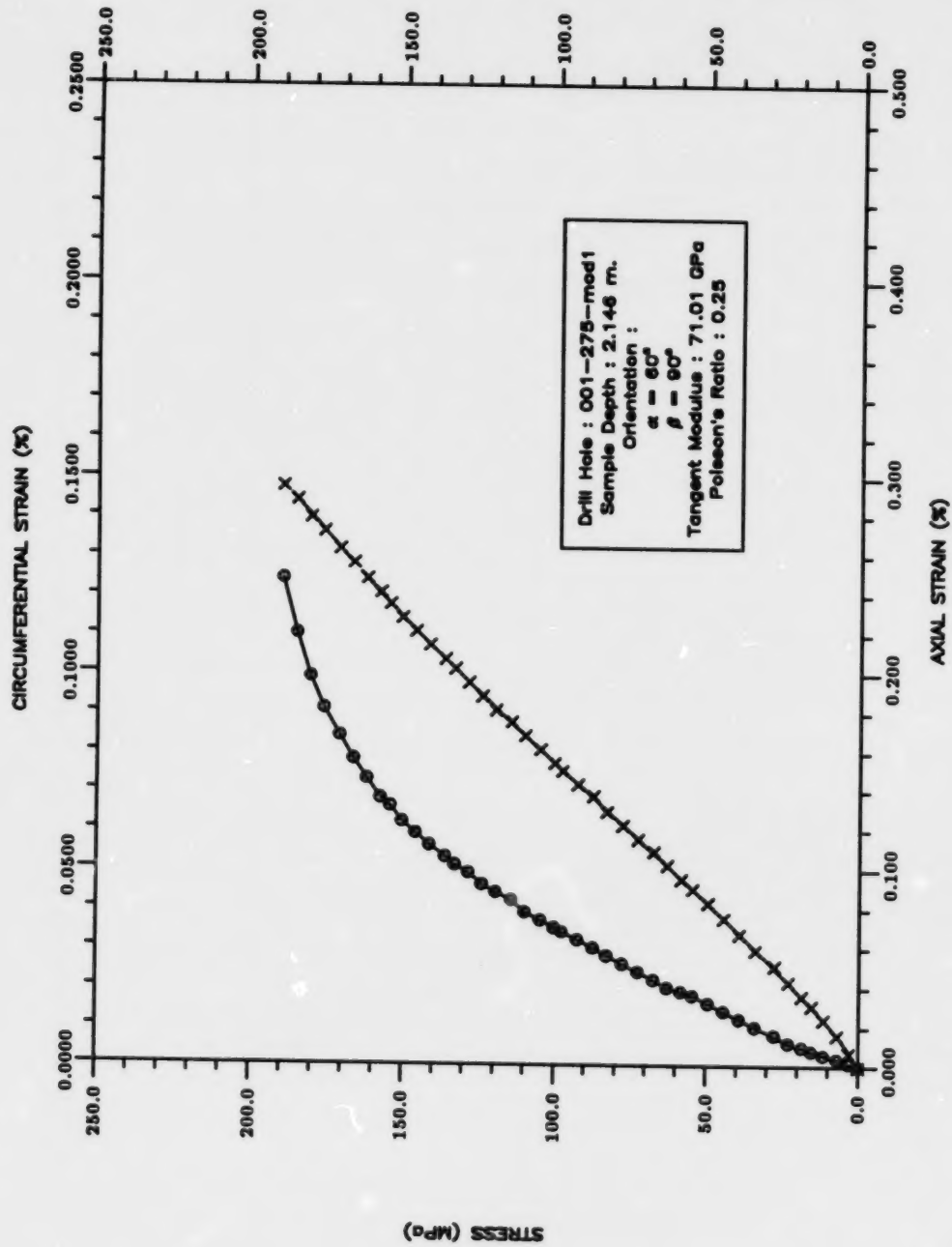


Fig. 4.3: Axial and circumferential stress/strain curves for anisotropy test specimens.

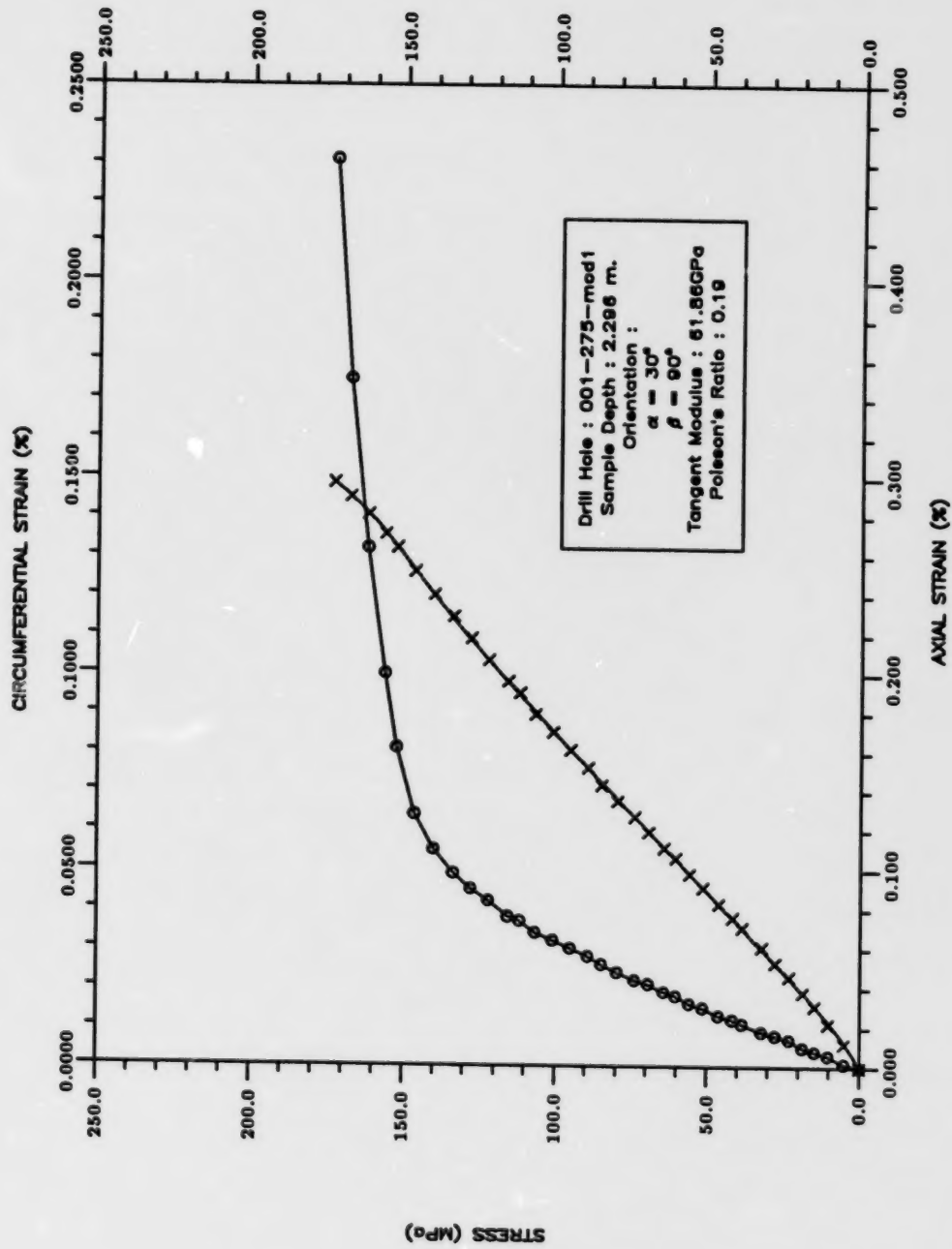


Fig.44: Axial and circumferential stress/strain curves for anisotropy test specimens.

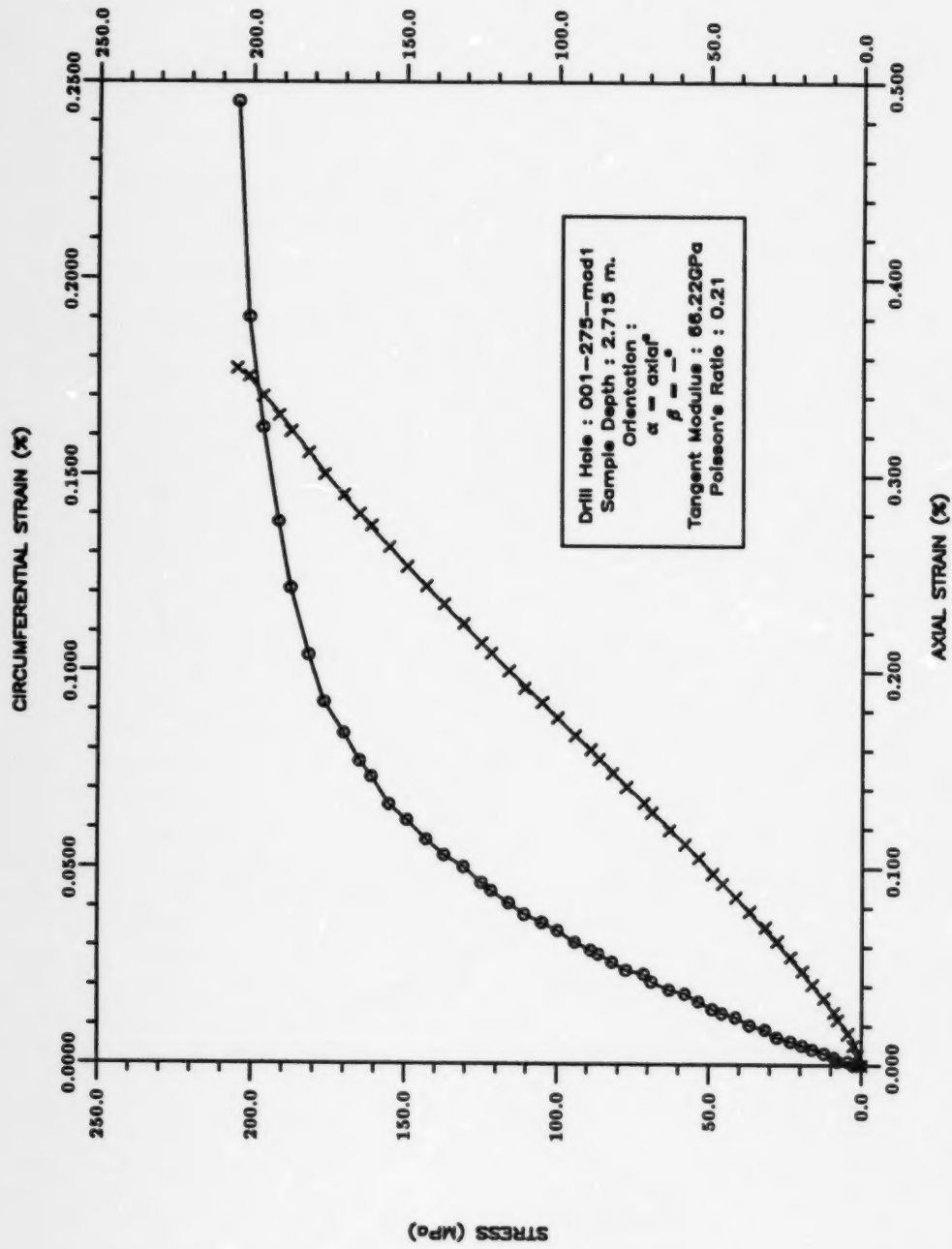


Fig. 45: Axial and circumferential stress/strain curves for anisotropy test specimens.

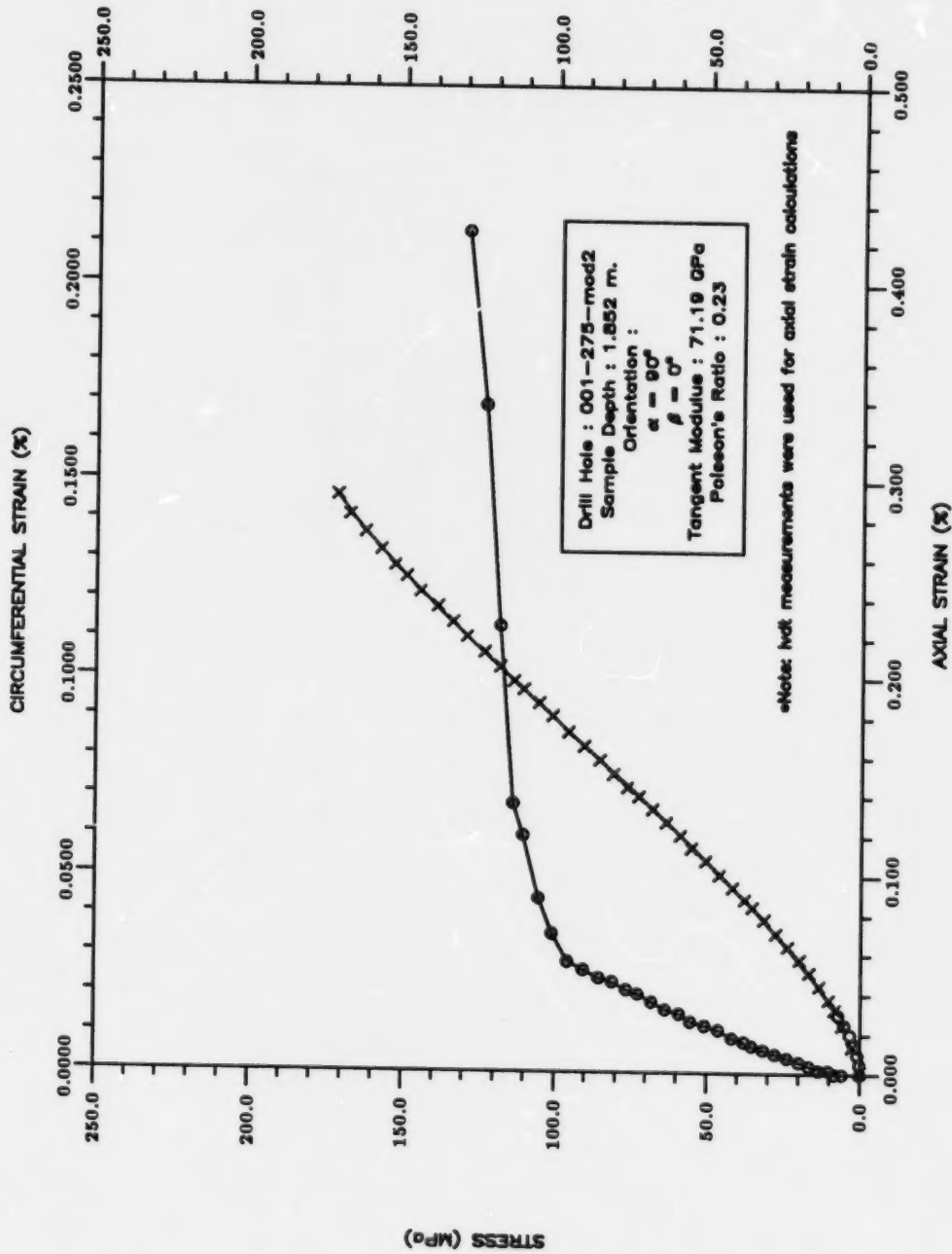


Fig.46: Axial and circumferential stress/strain curves for anisotropy test specimens.

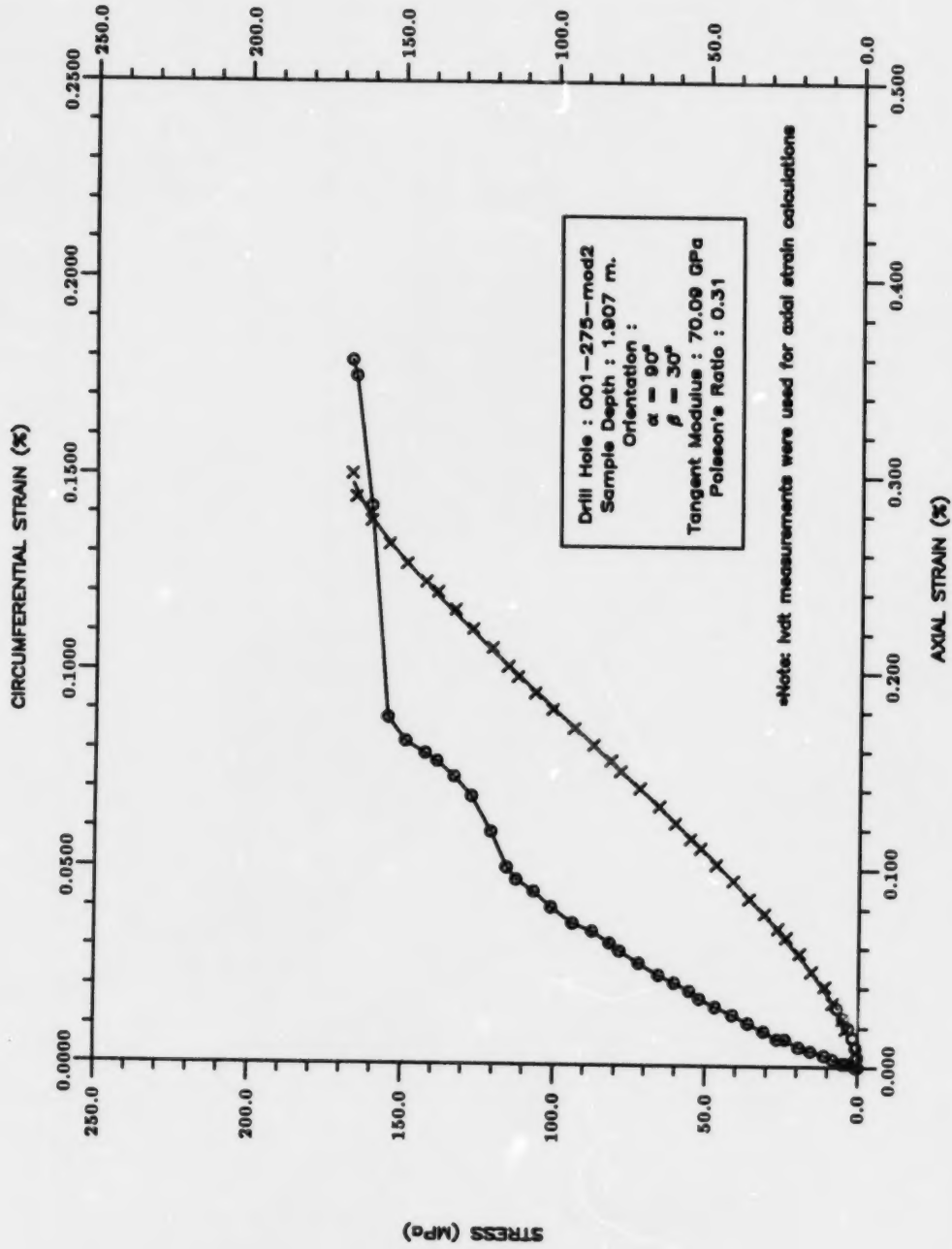


Fig. 47: Axial and circumferential stress/strain curves for anisotropy test specimens.

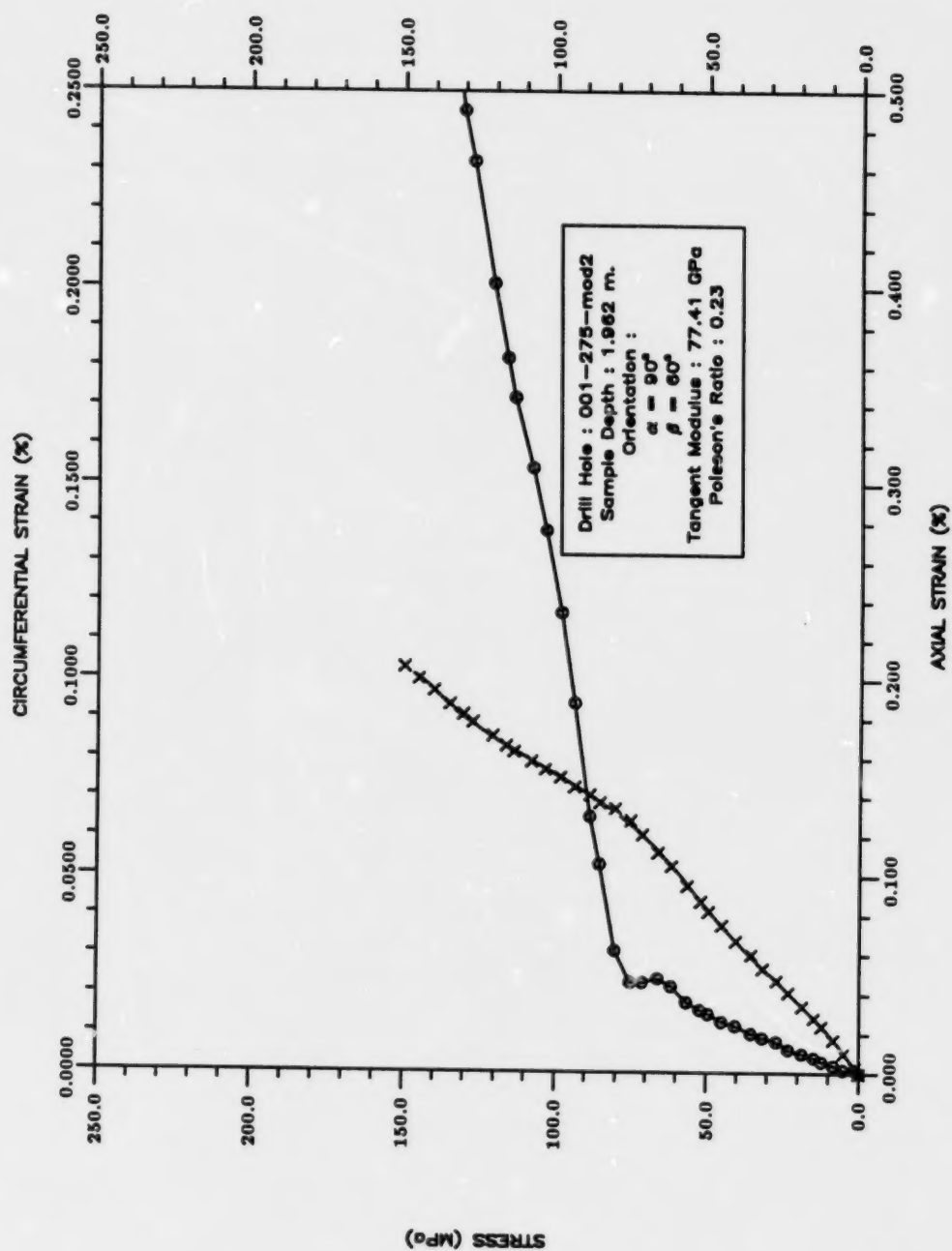


Fig.48: Axial and circumferential stress/strain curves for anisotropy test specimens.

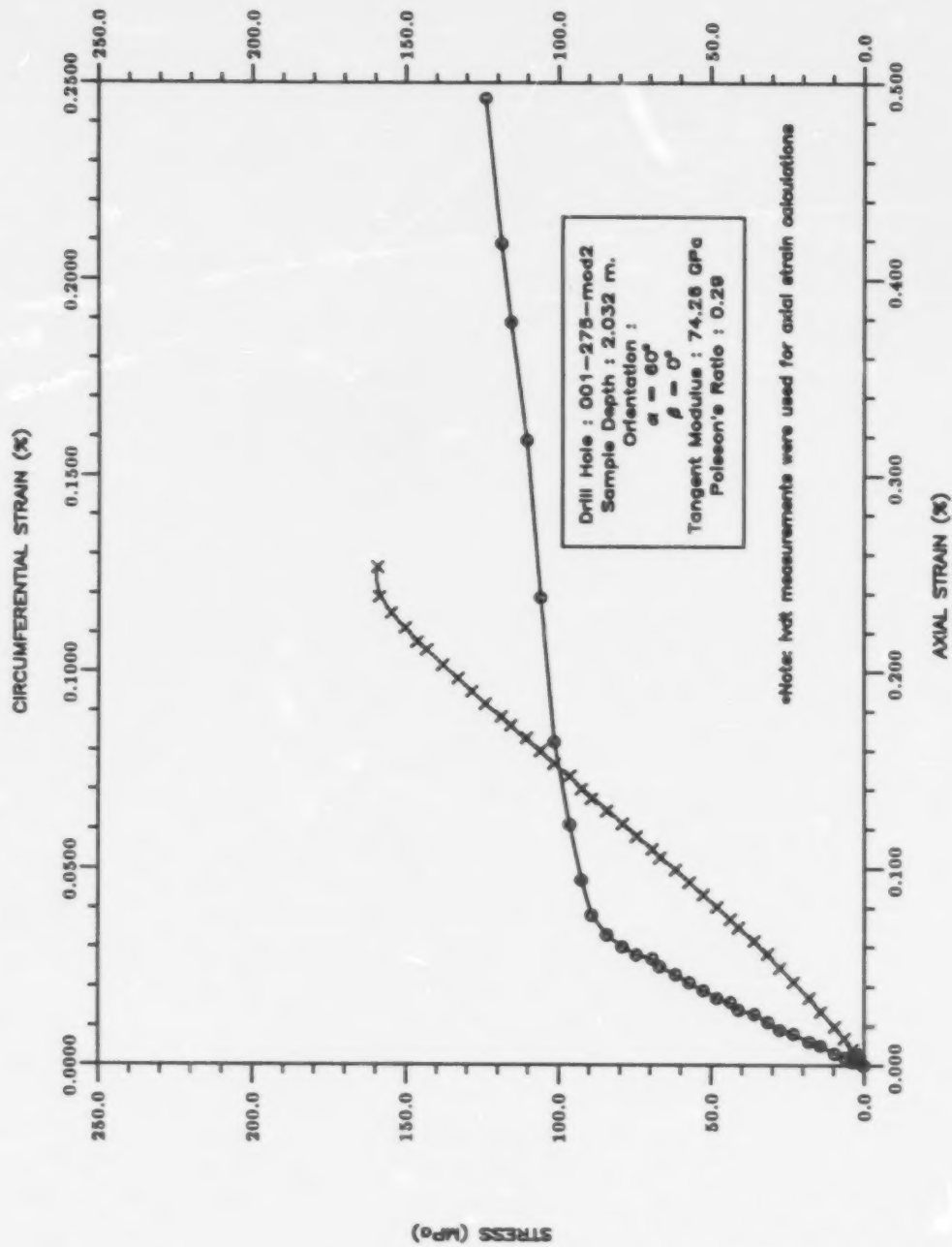


Fig. 49: Axial and circumferential stress/strain curves for anisotropy test specimens.

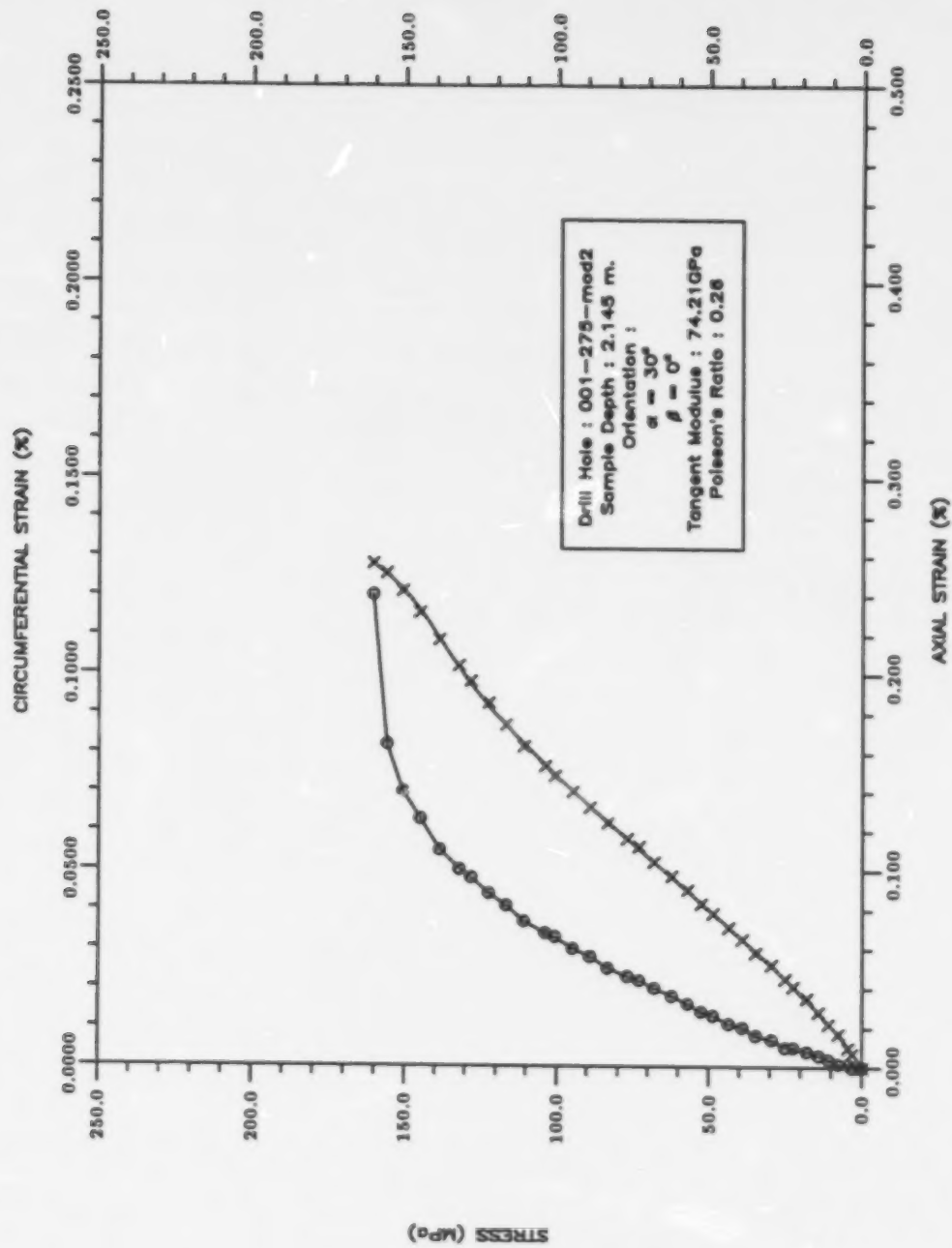


Fig. 50: Axial and circumferential stress/strain curves for anisotropy test specimens.

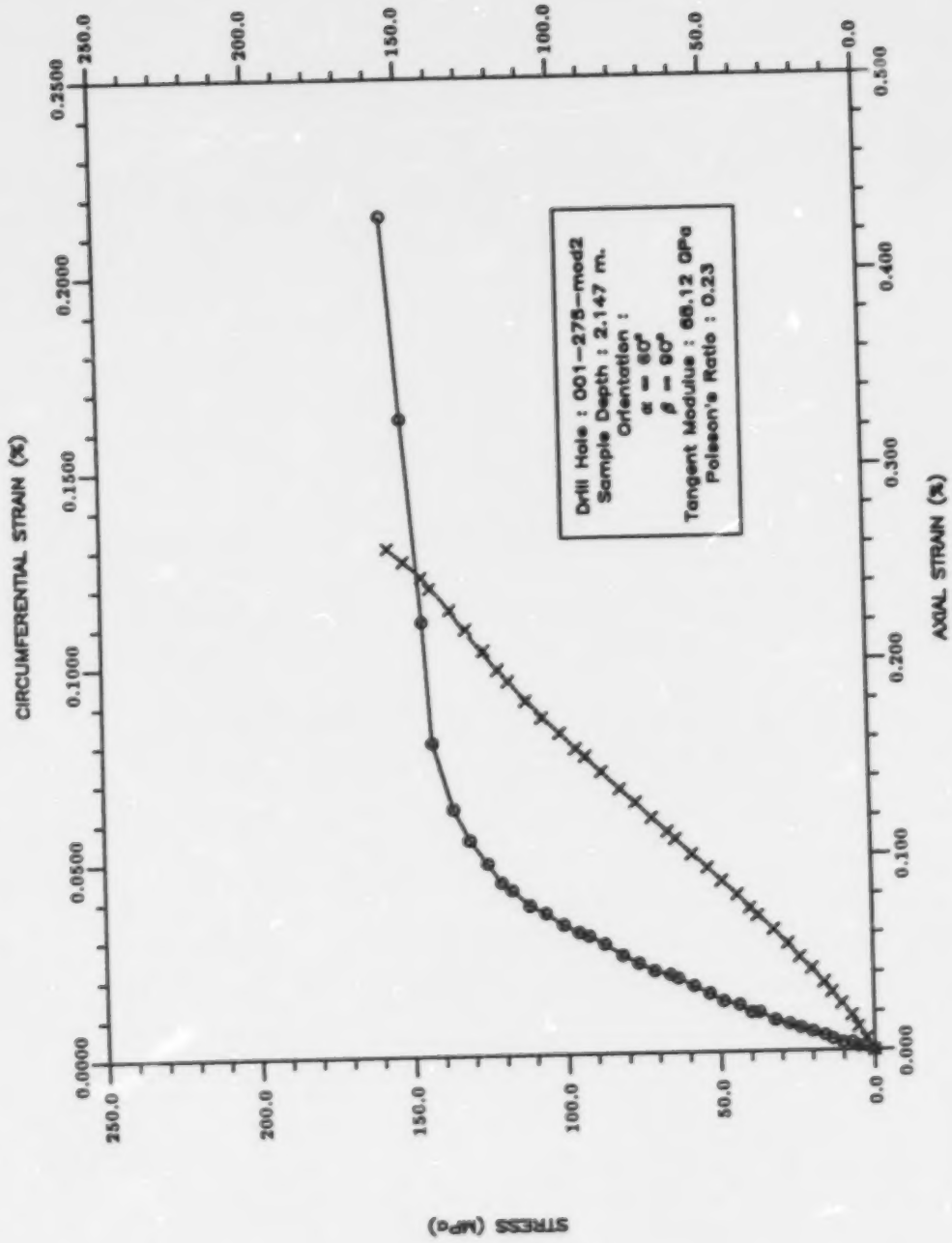


Fig. 5i: Axial and circumferential stress/strain curves for anisotropy test specimens.

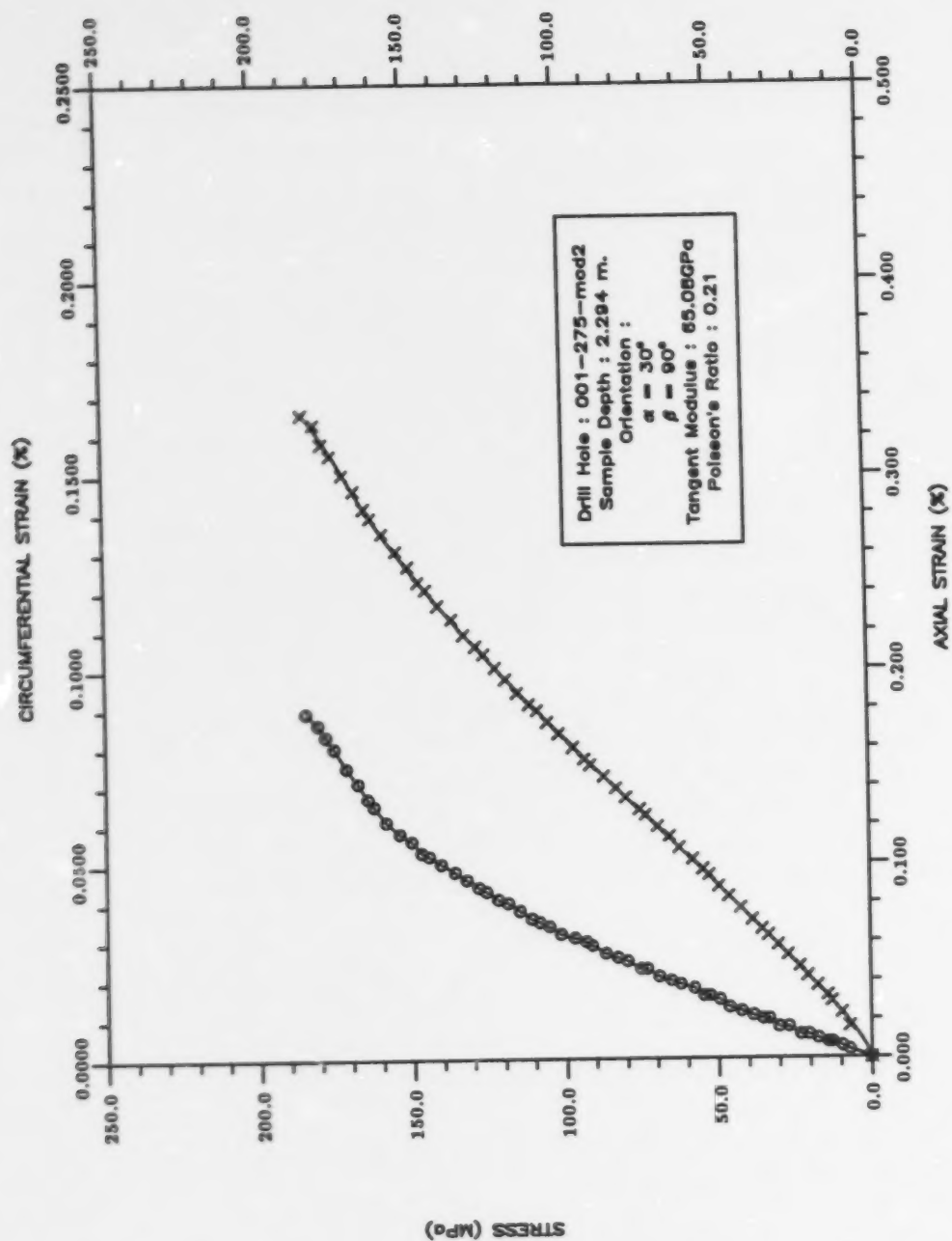


Fig. 52: Axial and circumferential stress/strain curves for anisotropy test specimens.

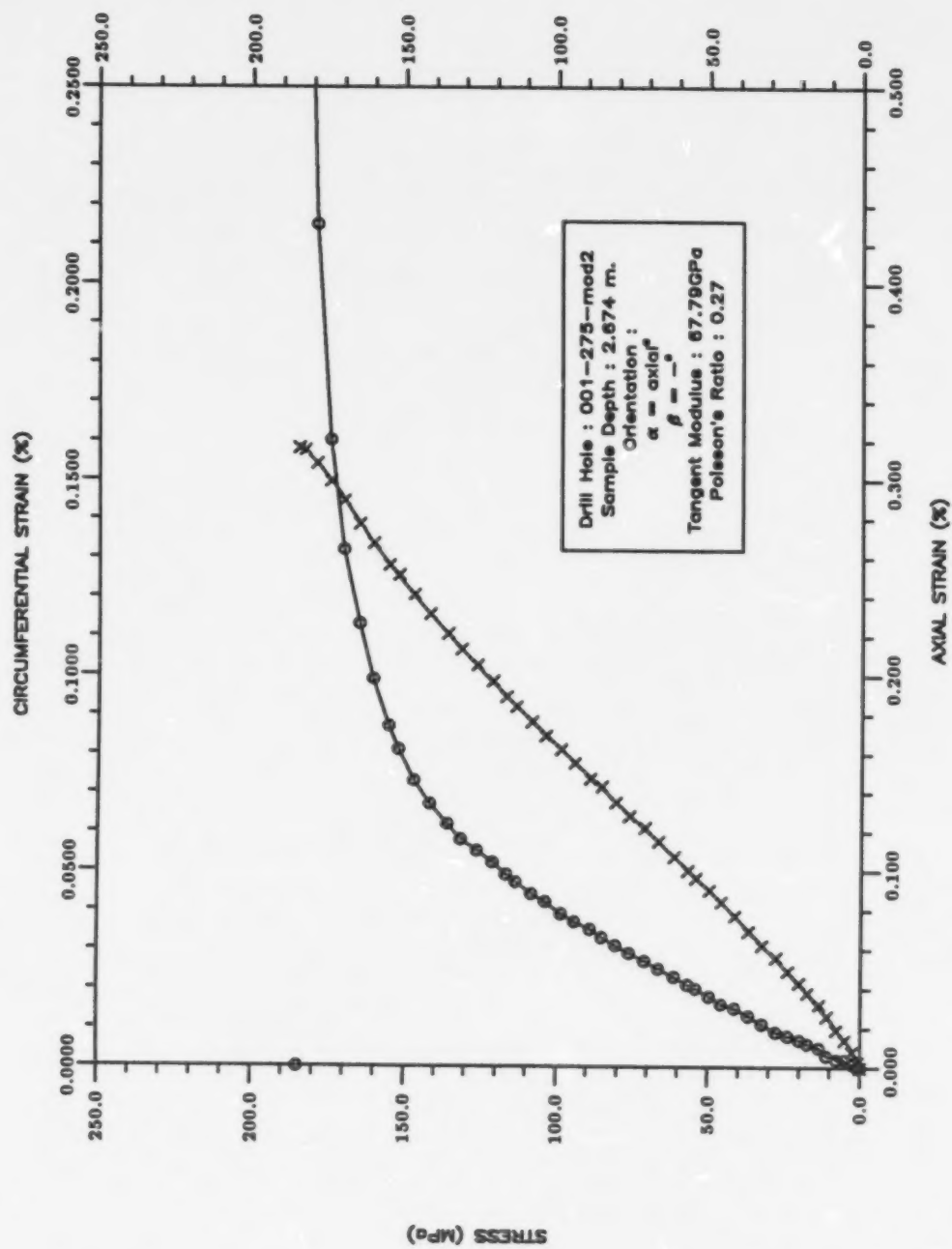


Fig. 53: Axial and circumferential stress/strain curves for anisotropy test specimens.

APPENDIX A

Atomic Energy  
of Canada  
Limited  
Nuclear Fuel  
Waste  
Management  
Whiteshell  
Nuclear Research  
Establishment

L'Energie Atomique  
du Canada  
Limitée  
Gestion des Déchets  
de Combustible  
Nucléaire  
Etablissement de  
Recherches Nucléaires  
de Whiteshell



Pinawa Manitoba  
R0E 1L0  
Ph(204)753-2311

1986 July 03

G-5410  
GSEB-86-152

Mr. Alfred Annor  
CANMET  
555 Booth Street  
OTTAWA, Ontario  
K1A 0G1

Dear Alfred:

The fourth batch of anisotropic properties samples will be sent to you this week. This batch consists of 54 samples from six 200 mm cores from drill hole numbers 001-072-MOD1, 001-072-MOD2, 001-228-MOD1, 001-228-MOD2, 001-275-MOD1, 001-275-MOD2.

The attachments give the details of the 200 mm drill hole locations, the system for describing the 45 mm core location and orientation, and photographs of the samples. The sampling method was described in the previous letter and attachments.

If you have any questions, please call me at (204) 345-8625.

Yours truly,

  
P. A. Lang  
Geotechnical Science and  
Engineering Branch

PAL/pyc

Attachments

cc: P. M. Thompson  
G. R. Simmons  
S. H. Whitaker  
S. M. Daley

## DESIGNATION OF ANISOTROPIC PROPERTIES SAMPLES

The location and orientation of the 200 mm diameter core hole numbers are as follows:

## 001-072-MOD1

Collar Coordinates : N 5,570,477.032  
E 295,787.329  
elev. 73.518  
Orientation : Plunge (dip): -00.20° (up)  
: Trend (direction): 040.98°

## 001-072-MOD2

Collar Coordinates : N 5,570,475.026  
E 295,787.969  
elev. 73.308  
Orientation : Plunge (dip): -00.39° (up)  
: Trend (direction): 101.04°

## 001-228-MOD1

Collar Coordinates : N 5,570,473.089  
E 295,785.897  
elev. 228.546  
Orientation : Plunge (dip): -01.16° (up)  
: Trend (direction): 158.72°

## 001-228-MOD2

Collar Coordinates : N 5,570,476.277  
E 295,787.783  
elev. 228.327  
Orientation : Plunge (dip): -00.32° (up)  
: Trend (direction): 062.09°

## 001-275-MOD1

Collar Coordinates : N 5,570,474.047  
E 295,786.956  
elev. 275.626  
Orientation : Plunge (dip): -01.26° (up)  
: Trend (direction): 155.12°

## 001-275-MOD2

Collar Coordinates : N 5,570,476.094  
E 295,787.377  
elev. 275.634  
Orientation : Plunge (dip): 00.00°  
: Trend (direction): 067.38°

The location and orientation of the 45 mm cores taken from the 200 mm cores are defined as follows:

- a) depth of the collar of the 45 m hole from the collar of the 200 mm hole.

- b) angle  $\beta$  gives the location of the collar of the 45 mm hole around the circumference of the 200 mm core. The angle is measured clockwise (looking down hole) from the orientation mark on the top of the core.
- c) angle  $\alpha$  is the angle between the core axis of the 45 mm core and the 200 mm core. The angle is measured clockwise (i.e., dip) from the down hole direction of the 200 mm core.

The depth, and  $\alpha$  and  $\beta$  angles are marked on each core, and on a label on water proof paper attached to each core. They are also listed in Tables 1 to 6.

In addition to these markings, there are two lines, an arrow, and  $\beta$  angle on the collar end of each 45 mm core (except the axial core). One line indicates the axial direction of the 200 mm core and the arrow points down hole. The short line across the axial line indicates the point at which the depth is measured. The 45 mm core that is parallel to the 200 mm core axis, contains the axial line and arrow marked along the top of the core. Pieces of core that are not suitable for testing, due to drill induced breaks, are marked "Do Not Test". Redrilling was not necessary because other pieces of the samples were more than 120 m in length.

#### Additional Information

##### 001-072-MOD1

200 mm Core: Two pieces 1.260 m to 1.855 m  
1.855 m to 2.657 m  
Fracture at 2.657 m

Three samples were redrilled due to drill induced breaks, resulting in samples being unsuitable for testing. Original locations are marked with an "x" on the photographs. They are listed below.

|                          | <u>ORIGINAL LOCATION</u> | <u>REDRILLED LOCATION</u> |
|--------------------------|--------------------------|---------------------------|
| Axial                    | 1.855 m                  | 1.855 m                   |
| $\alpha$ 30° $\beta$ 0°  | 1.522 m                  | 2.283 m                   |
| $\alpha$ 60° $\beta$ 90° | 1.985 m                  | 2.058 m                   |

##### 001-072-MOD2

200 mm Core: Two pieces 1.417 m to 2.132 m  
2.132 m to 2.692 m  
Fracture at 1.417 m and 2.692 m

One sample was redrilled due to a drill induced break and is listed below.

|       | <u>ORIGINAL LOCATION</u> | <u>REDRILLED LOCATION</u> |
|-------|--------------------------|---------------------------|
| Axial | 2.132 m                  | 2.132 m                   |

S. M. Daley  
1986 July 03

TABLE 1

DRILL HOLE NO. 001-072-MOD1  
1.260 m to 2.657 m  
MARK TOP OF HOLE AND AXIAL DIRECTIONS

| DEPTH (m) | $\alpha$<br>(From<br>Axial) | $\beta$<br>(Around<br>Circumference) | DATE<br>DRILLED |
|-----------|-----------------------------|--------------------------------------|-----------------|
| 1.290     | 90°                         | 30°                                  | 86-06-17        |
| 1.345     | 90°                         | 0°                                   | 86-06-17        |
| 1.395     | 90°                         | 60°                                  | 86-06-17        |
| 1.448     | 90°                         | 90°                                  | 86-06-17        |
| 1.460     | 60°                         | 0°                                   | 86-06-18        |
| 1.855     | 0°                          | Axial Core                           | 86-06-16        |
| 2.058     | 60°                         | 90°                                  | 86-06-18        |
| 2.158     | 30°                         | 90°                                  | 86-06-20        |
| 2.283     | 30°                         | 0°                                   | 86-06-20        |

TABLE 2

DRILL HOLE NO. 001-072-MOD2  
1.417 m to 2.692 m  
MARK TOP OF HOLE AND AXIAL DIRECTIONS

| DEPTH (m) | $\alpha$<br>(From<br>Axial) | $\beta$<br>(Around<br>Circumference) | DATE<br>DRILLED |
|-----------|-----------------------------|--------------------------------------|-----------------|
| 1.497     | 90°                         | 0°                                   | 86-06-17        |
| 1.550     | 90°                         | 30°                                  | 86-06-17        |
| 1.604     | 90°                         | 60°                                  | 86-06-17        |
| 1.659     | 90°                         | 90°                                  | 86-06-17        |
| 1.667     | 60°                         | 0°                                   | 86-06-18        |
| 1.759     | 30°                         | 0°                                   | 86-06-20        |
| 2.132     | 0°                          | Axial Core                           | 86-06-16        |
| 2.215     | 60°                         | 90°                                  | 86-06-18        |
| 2.309     | 30°                         | 90°                                  | 86-06-20        |

TABLE 3

DRILL HOLE NO. 001-228-MOD1  
3.380 m t 4.180 m  
MARK TOP OF HOLE AND AXIAL DIRECTIONS

| DEPTH (m) | $\alpha$<br>(From<br>Axial) | $\beta$<br>(Around<br>Circumference) | DATE<br>DRILLED |
|-----------|-----------------------------|--------------------------------------|-----------------|
| 3.414     | 90°                         | 0°                                   | 86-06-17        |
| 3.470     | 90°                         | 30°                                  | 86-06-17        |
| 3.525     | 90°                         | 60°                                  | 86-06-17        |
| 3.580     | 90°                         | 90°                                  | 86-06-17        |
| 3.590     | 60°                         | 0°                                   | 86-06-18        |
| 3.695     | 30°                         | 0°                                   | 86-06-19        |
| 3.690     | 60°                         | 90°                                  | 86-06-18        |
| 3.835     | 30°                         | 90°                                  | 86-06-19        |
| 4.180     | 0°                          | Axial Core                           | 86-06-16        |

TABLE 4

DRILL HOLE NO. 001-228-MOD2  
3.446 m to 4.342 m  
MARK TOP OF HOLE AND AXIAL DIRECTIONS

| DEPTH (m) | $\alpha$<br>(From<br>Axial) | $\beta$<br>(Around<br>Circumference) | DATE<br>DRILLED |
|-----------|-----------------------------|--------------------------------------|-----------------|
| 3.488     | 90°                         | 0°                                   | 86-06-16        |
| 3.543     | 90°                         | 30°                                  | 86-06-17        |
| 3.598     | 90°                         | 60°                                  | 86-06-17        |
| 3.653     | 90°                         | 90°                                  | 86-06-17        |
| 3.674     | 60°                         | 0°                                   | 86-06-18        |
| 3.791     | 30°                         | 0°                                   | 86-06-19        |
| 3.791     | 60°                         | 90°                                  | 86-06-18        |
| 3.943     | 30°                         | 90°                                  | 86-06-19        |
| 4.342     | 0°                          | Axial Core                           | 86-06-16        |

TABLE 5

DRILL HOLE NO. 001-275-MOD1  
1.806 m to 2.715 m  
MARK TOP OF HOLE AND AXIAL DIRECTIONS

| DEPTH (m) | $\alpha$<br>(From<br>Axial) | $\beta$<br>(Around<br>Circumference) | DATE<br>DRILLED |
|-----------|-----------------------------|--------------------------------------|-----------------|
| 1.850     | 90°                         | 0°                                   | 86-06-17        |
| 1.905     | 90°                         | 30°                                  | 86-06-17        |
| 1.960     | 90°                         | 60°                                  | 86-06-17        |
| 2.015     | 90°                         | 90°                                  | 86-06-17        |
| 2.033     | 60°                         | 0°                                   | 86-06-18        |
| 2.144     | 30°                         | 0°                                   | 86-06-19        |
| 2.146     | 60°                         | 90°                                  | 86-06-18        |
| 2.296     | 30°                         | 90°                                  | 86-06-19        |
| 2.715     | 0°                          | Axial Core                           | 86-06-16        |

TABLE 6

DRILL HOLE NO. 001-275-MOD2  
1.807 ■ to 2.674 ■  
MARK TOP OF HOLE AND AXIAL DIRECTIONS

| DEPTH (m) | $\alpha$<br>(From<br>Axial) | $\beta$<br>(Around<br>Circumference) | DATE<br>DRILLED |
|-----------|-----------------------------|--------------------------------------|-----------------|
| 1.852     | 90°                         | 0°                                   | 86-06-17        |
| 1.907     | 90°                         | 30°                                  | 86-06-17        |
| 1.962     | 90°                         | 60°                                  | 86-06-17        |
| 2.017 —   | 90°                         | 90°                                  | 86-06-17        |
| 2.032     | 60°                         | 0°                                   | 86-06-18        |
| 2.145     | 30°                         | 0°                                   | 86-06-19        |
| 2.147     | 60°                         | 90°                                  | 86-06-18        |
| 2.294     | 30°                         | 90°                                  | 86-06-19        |
| 2.674     | 0°                          | Axial Core                           | 86-06-16        |



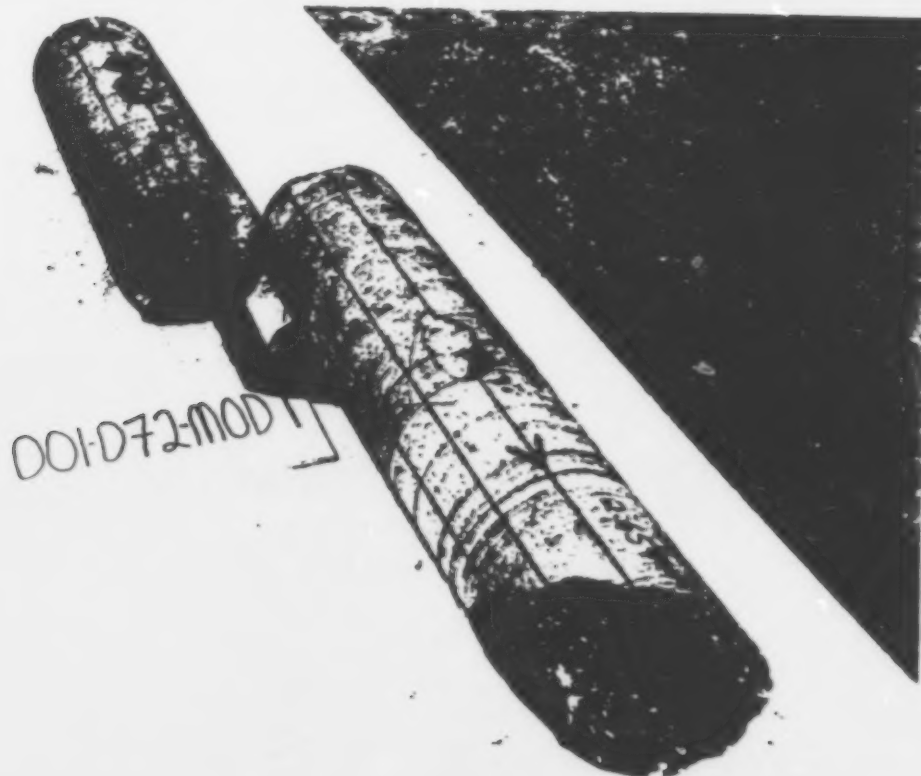
001-072-MOD 2



001-072-MOD 2'



001-072-MOD 1

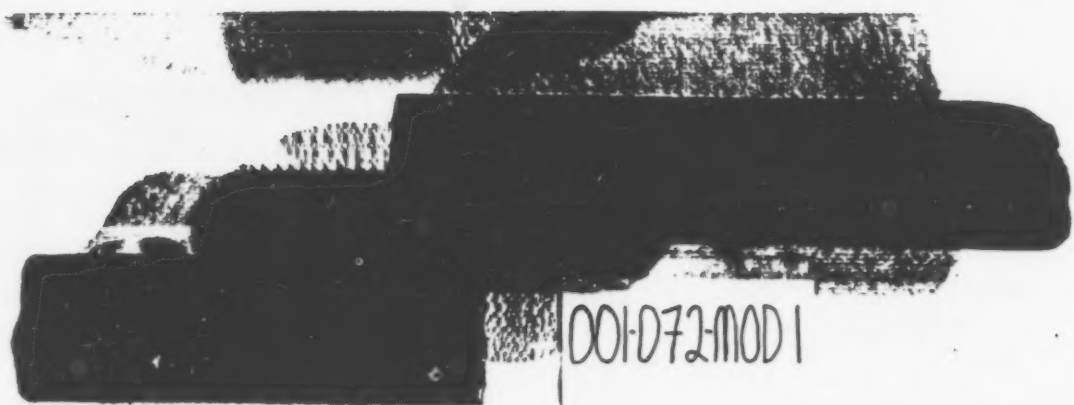


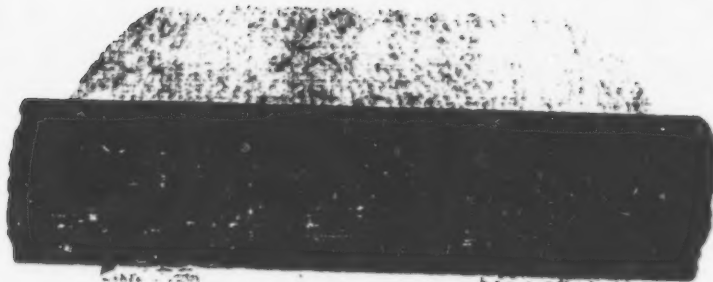


001-072-MOD 2



001-072-MOD 2





001-228-MOD1



001-228-MOD1



001-228-MOD1



001-228-MOD1



00F228-MOD2



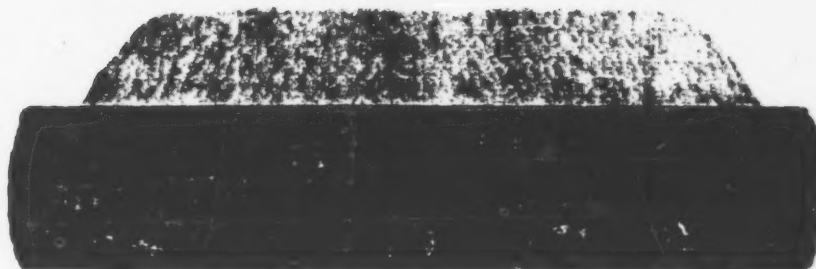
00F228-MOD2



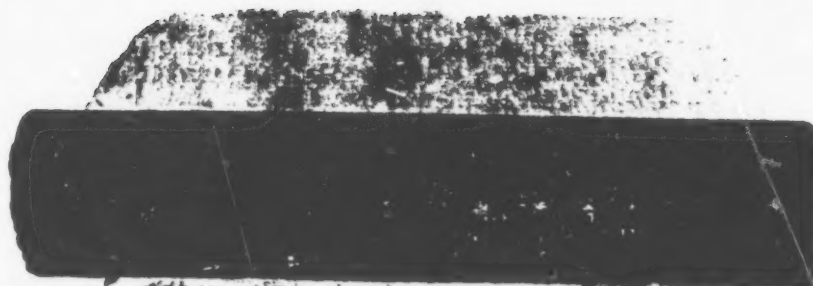
00F-228-MOD2



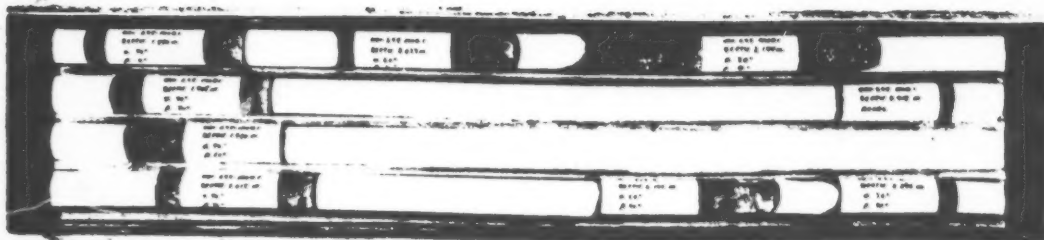
00F-228-MOD2



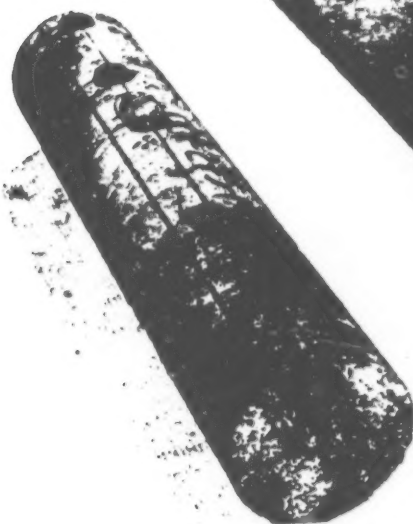
001-275-MOD1



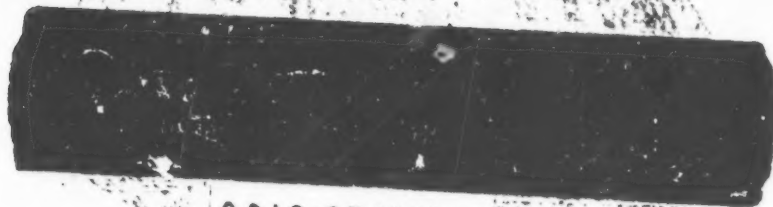
001-275-MOD1



001-275-MOD1



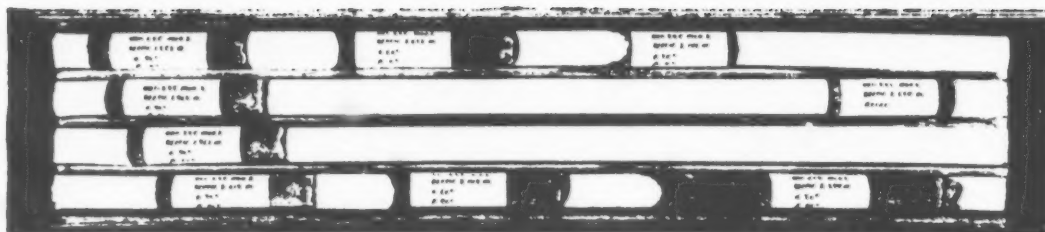
001-275-MOD1



001-275-MOD 2



001-275-MOD 2



001-275-MOD 2



001-275-MOD 2